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NASA Contractor Report 3502

Environmental Exposure Effects on Composite Materials for Commercial Aircraft

Martin N. Gibbins and Daniel J. Hoffman

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Environmental Exposure Effects on Composite Materials for Commercial Aircraft

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Boeing Commercial Airplane Company
Seattle, Washington

Prepared for
Langley Research Center
under Contract NAS1-15148

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and Space Administration

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1982

FOREWORD

This document is an interim technical report executed in response to the statement of work for contract NAS1-15148, Environmental Exposure Effects on Composite Materials for Commercial Aircraft. The work was conducted from November 1977 to July 1981. The contract develops long-term environmental durability data and is scheduled to continue until 1988. This report covers specimen design, fabrication, and deployment for both long-term and accelerated laboratory testing. Some test results from both long-term and accelerated exposure also are included.

Work on this contract is being performed by the Advanced Structural Concepts organization. Key personnel associated with the program during the reporting period and their area of responsibility are:

J. E. McCarty	Program Manager
D. J. Hoffman	Technical Leader*
M. N. Gibbins	Test and Analysis
M. W. Ledbury	Materials
B. D. Parashar	Quality Assurance
J. S. Chen	Chemical Analysis

The International System of Units (with parenthetic U.S. equivalents) is used for physical quantities throughout this report. Measurements and calculations were made in U.S. customary units.

*Because D. J. Hoffman is no longer with Boeing, M. N. Gibbins has been named Technical Leader.

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1.0 SUMMARY

A combined analytical and experimental program is being conducted to evaluate the influence of aircraft-associated environments on the environmental resistance of commercially available composite material systems. Expanded use of composite materials in primary aircraft structure requires an improved understanding of the environmental durability of these material systems. This report covers the first 3 years of a planned 11-year program.

The basic program uses T300/5208, T300/5209, and T300/934 graphite-epoxy composite materials. AS-1/3501-6 graphite-epoxy and Kevlar 49/F161-188 Kevlar-epoxy composite materials were added to the program as optional materials 2 years after its start. This report presents results from only the basic program. Materials were purchased and evaluated for mechanical and chemical baseline properties before exposure. Large groups of specimens were then weighed, measured, assembled into fixtures, and deployed for exposure. Sets of specimens were sent to three commercial airlines for deployment aboard Boeing model 737 aircraft flying in daily revenue service. The airlines chosen for their willingness to support the required tasks and to provide a variety of flight environments were Air New Zealand, Ltd., Aloha Airlines, and Southwest Airlines. Other sets of specimens were sent to four different ground exposure sites. Three locations were major operating bases of the three airlines involved in the program. The fourth site, NASA-Dryden Flight Research Center, was selected to give a broad range of climatic features. Sufficient ground and aircraft specimens were deployed to permit returns and postexposure evaluation after 1, 2, 3, 5, 7, and 10 years.

Sets of specimens also were deployed to various controlled laboratory environments. The six laboratory exposures ranged from simple time alone to a complex programmed temperature, pressure, humidity chamber that simulated an aircraft ground-air-ground (GAG) cycle.

After two years of long-term exposure, the tension and flexure specimen configurations have shown little or no residual strength decreases from baseline values. Some specimens have shown residual strength increase. The short beam shear strength values, however, have shown greater strength reductions particularly at the wetter environments.

The laboratory exposure results show the short beam shear specimens are somewhat more sensitive to laboratory environment than are the other configurations.

2.0 INTRODUCTION

With the advent of rising fuel costs, a number of Boeing- and NASA-sponsored programs have been initiated to improve the operating efficiency of commercial transport aircraft (refs. 1 and 2). One method of improving efficiency is to reduce aircraft structural weight (refs. 1 and 3).

Composite materials have been introduced to secondary structural components in scheduled commercial service (refs. 3 and 4). Their use has demonstrated both weight savings and confidence in current design applications and fabrication methods. These secondary structures, however, account for a relatively small amount of the total aircraft structural weight. A much greater weight savings potential exists in components such as the wing and fuselage. If the confidence currently experienced by composites in secondary structural applications is to be extended to primary structure, the effects of long-term exposure to the aircraft operating environment must be better understood.

It is well known that composite laminates will absorb moisture given the correct conditions. It also is known that absorbed moisture can degrade the mechanical properties of composite laminates, particularly at elevated temperatures. Since aircraft components are frequently exposed to atmospheric moisture, rain, and accumulated (trapped) water, quantitative data are required showing the amount of fluids absorbed under various conditions and the effect of this absorption on mechanical properties.

The science of composite materials is relatively new and hence, rapidly changing. To take advantage of the advances in this maturing science, it will be necessary to understand how to test for and predict long-term durability from short-term accelerated tests. Accelerated laboratory test techniques must be developed that are capable of reliably predicting long-term durability.

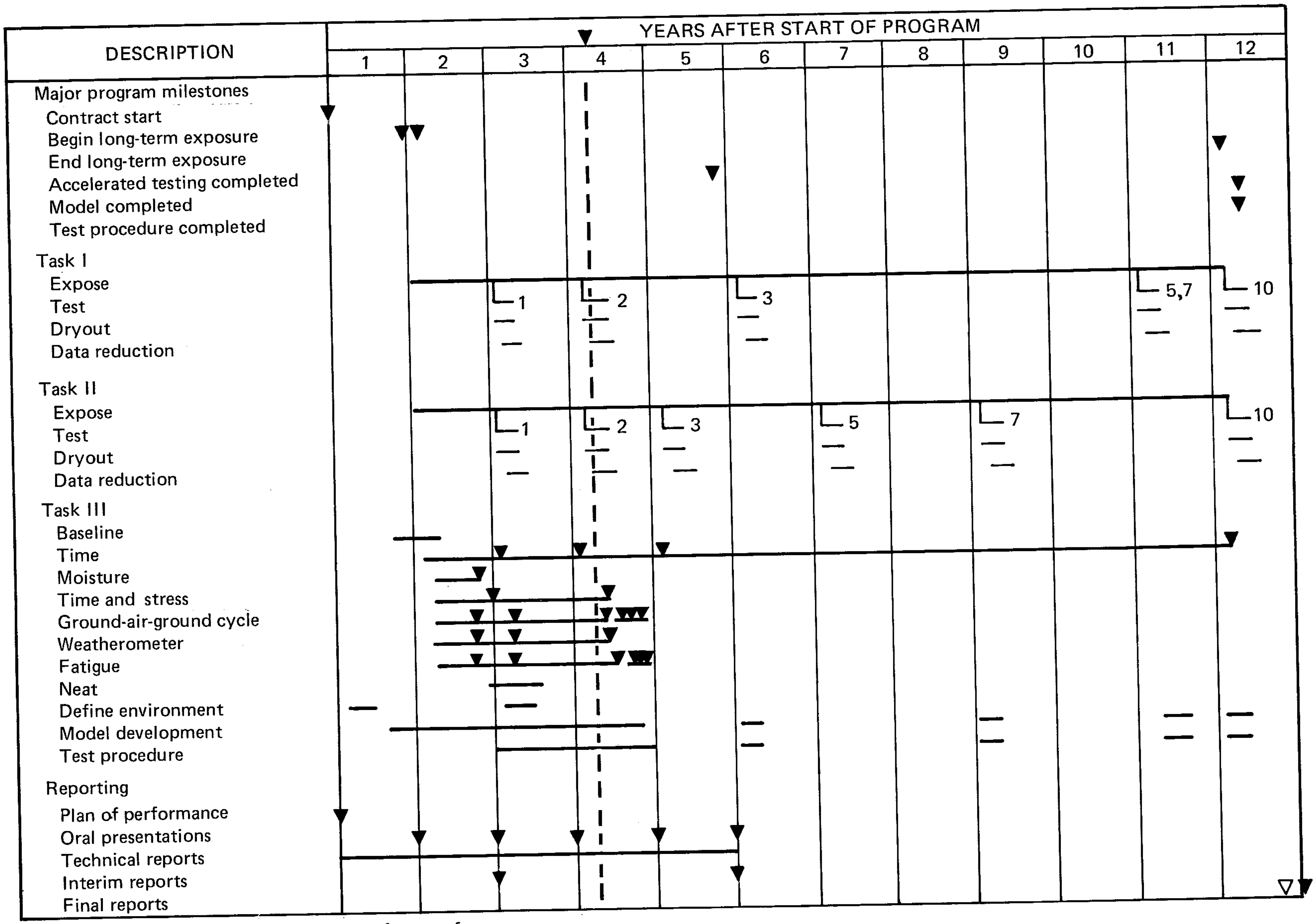
This contract will expand, and in some cases establish, the long-term data base for composite materials as they are affected by inflight and on-the-ground aircraft operational environments. The study also includes a task to develop an accelerated environmental test procedure and to correlate long- and short-term results. This will lead to an analytical model capable of predicting the long-term environmental durability of composites.

The overall program has a duration of 11 years and is performed in three tasks:

- Task I--Flight Exposure
  - Confidence through long-term exposure data
  - Interior and exterior exposure on three different airlines for times up to 10 years
  - Over 5300 specimens
- Task II--Ground Exposure
  - Confidence through long-term exposure data
  - Solar and nonsolar exposure at four different ground stations for times up to 10 years
  - Over 5300 specimens
- Task III--Accelerated Environmental Effects and Data Correlation
  - Baseline testing
  - Accelerated tests to look at the effects of time, temperature, stress, moisture, weatherometer, and GAG simulation
  - Over 4300 specimens
  - Analytical model for durability prediction

- Recommended accelerated test procedures for evaluating environmental resistance

The program includes inflight and ground exposure for durations up to 10 years and will obtain mechanical strength data from approximately 17 000 specimens representing five different composite material systems. Physical and chemical property data also will be extracted from selected specimens. The program schedule is shown in Figure 1.



Note: Numbers on bar chart are numbers of years of exposure.

Figure 1. Program Schedule

3.0 SYMBOLS AND ABBREVIATIONS

C_v	coefficient of variation
D_{11}	bending stiffness
E	Young's modulus
GAG	ground-air-ground
NDI	nondestructive inspection
t	specimen thickness
T_g	glass transition temperature
W	specimen width
QI	quasi-isotropic
R&D	research and development
RH	relative humidity
RT	room temperature
UV	ultraviolet
ε	strain
δ	deflection
μ	microstrain at fracture
σ	stress

4.0 AIRPLANE-ASSOCIATED ENVIRONMENT

To predict the environmental durability of composite materials for commercial airplane service, it is first necessary to define the environment to which these materials will be exposed. This is considered a difficult but critical step for several reasons.

First, the exact mechanisms of long-term composite degradation are unknown. This means that the environmental definition must be flexible enough to account for a variety of degradation modes.

Second, the list of environmental factors that may affect composites is lengthy but manageable. It includes temperature, humidity, fuels, fluids, ultraviolet (UV) radiation, and others. The complexity results because these items rarely occur alone, and realistic combinations must be established. Care must be exercised to avoid taking worst cases of individual factors and combining them to produce a case that is not realistic.

Third, the anticipated exposure will vary significantly with the particular airplane model, airline, and component on the aircraft. The challenge is to combine all of these factors into a manageable definition of aircraft-associated environment.

The first step in the environmental definition is time alone. It is important because it defines how long (or for how many cycles) the material system or component must endure all of the adverse environmental factors. A complete description of the program content was given in the first quarterly report (ref. 5). Other reports (refs. 6 through 14) have covered progress to date.

An airplane calendar lifetime goal of 20 years is somewhat arbitrary but is widely accepted throughout the commercial transport industry as an unofficial target. In the future, the 20-year life may actually prove to be conservative. Rapidly rising fuel prices have resulted in more research designed to improve fuel efficiency. This program is part of that increased research and development (R&D) effort. As more fuel-efficient aircraft are developed, carriers may modernize their fleets more often. Boeing estimates that one out of every two aircraft sold in the future represents a replacement for an existing, aging aircraft. The older airplanes may be passed on to second- and third-tier owners and ultimately, the oldest and least economically efficient airplanes are retired.

The second factor that must be considered in the environmental definition is how the aircraft is used. This varies with the model of aircraft and the carrier. Airplanes are designed to fill particular range and payload requirements. Different models, therefore, have significantly varying mission profiles. Furthermore, a fleet of a particular aircraft model will have different utilization rates and mission profiles depending on the route structure of the carrier. This is specifically true of the regional carriers and the shorter range aircraft. As an example, Aloha Airlines operates a fleet of Boeing model 737 aircraft wholly within the Hawaiian Islands. The average flight length is 28 minutes. Although not participating in this contract, Frontier Airlines provides a good contrast. It operates the same aircraft over a 26-state region plus Canada and Mexico and has an average flight length of 60 minutes.

Finally, most individual aircraft will normally have a mission mix. As an example, United Airlines flight no. 44 originates in Seattle, Washington and flies to Portland, Oregon (132 statute miles), continues to Salt Lake City (630 statute miles), and terminates in Washington, D.C. (1839 statute miles). In a single day, this aircraft flies a short, medium, and relatively long-range flight.

The Boeing Company has made extensive studies on its jet fleet statistics. The results of these studies account for various models, utilization rates, and mission mix. This methodology is ideally suited for describing the utilization data required for an environmental durability analysis.

The initial step in this procedure is to determine the number of life flights. Utilization histories are accounted for by requiring an aircraft design for short, medium, and long flight lengths. The long flight length is a percentage of the maximum range based on the most economical operations with a fixed percentage of design payload. Each aircraft model (737 or 747) will have a different long flight length and hence, different medium and short lengths. The design requirement for long, medium, and short flights takes into account different ways each aircraft model may be used. A short- and a long-range aircraft will be used as an example.

Aircraft with short flight lengths are used less on a daily average than those with long flight lengths. This is due to various reasons such as increased ground time requirements, passenger load and unload, and galley servicing. It is also due to the route structure that a short-range aircraft conventionally flies, as opposed to that of a long-range aircraft. The flight length and the utilization rate per day can be used to calculate the flights for the 20-year timespan.

Once the number of flights has been determined, the next step is to ascertain when the aircraft flies and when it sits on the ground. Figure 2 shows various possibilities. The day flier is typical of most short-range aircraft and to a lesser degree, of all aircraft. Curfew requirements on many of the world's major airports limit the number of arrivals and departures occurring between approximately midnight and 6 a.m.

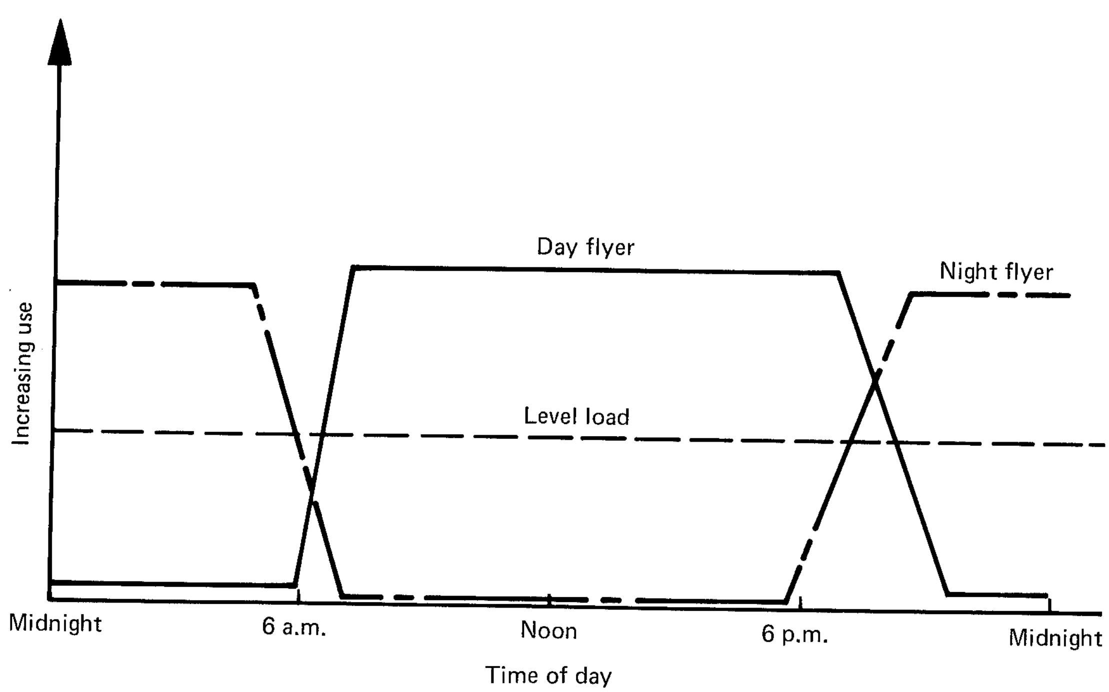


Figure 2. Typical Aircraft Uses

The level line curve represents freighter aircraft and combined passenger-freighter aircraft. Basically, the use remains constant throughout the 24-hour period. The night-flying aircraft is a less prevalent case and probably limited largely to long-range aircraft. Studies are being performed to determine whether or not some of these profiles can be eliminated from further analysis. This data, coupled with a particular airline route structure (climate), will determine the aircraft macroenvironment. This macroenvironment must now be modified to account for solar heating, convective cooling, moisture condensation, rain, and surface coatings.

One way to manage numerous environmental variables is to study the ways the material can fail. Generally, a material fails from prolonged, extreme, or repetitive exposure to a given set of conditions. Using temperature as an example, failure can be caused by heat aging due to long exposure periods in a hot arid desert climate or due to exposure to a temperature extreme (i.e., being in the proximity of but not directly involved in a fire). A material also might fail because it is subject to a large number of freeze-thaw cycles.

The exposure sites and conditions for aircraft, ground rack, and laboratory simulation were selected to represent temperature cycles plus moisture, stress, and solar radiation variations. Exterior aircraft exposure provides the most severe cycles of temperature and moisture in commercial airplane service. Interior aircraft exposure involves a milder climate. Ground-based exposure will not involve the extreme cold of the aircraft exposure but will provide a method for determining specific effects of flight on the materials. The laboratory simulation then can be compared with the accelerated environmental exposure.

5.0 MATERIALS AND PROCESSES

5.1 MATERIAL SELECTION

This study is being conducted to develop a long-term environmental data base and to better understand the mechanism and extent of composite material degradation in the commercial transport aircraft environment. Individual materials were selected because of their prior use in components or because they provide discrete variables in the durability study.

Identification of commercial products in this report is used to adequately describe the test materials. Neither the identification of these commercial products nor the results of the investigation published herein constitutes official endorsement, expressed or implied, of any such product by either The Boeing Company or NASA.

Five materials were selected for evaluation:

- Narmco T300/5208 (material A)
- Narmco T300/5209 (material B)
- Fiberite T300/934 (material C)
- Hercules AS-1/3501-6 (material D)
- Hexcel Kevlar 49/F161-188 (material E)

The T300/5208 system was selected because of its widespread use on components currently in service. The T300/934 system was selected because of its chemical and cure similarities to the 5208 system.

The T300/5209 system was selected because it is a 121°C (250°F) curing system and because it has been used successfully on the NASA-sponsored 737 graphite-epoxy spoiler evaluation.

The AS-1/3501-6 system was selected because of its significant usage, primarily in military aircraft, and because it affords an opportunity to look at the AS fiber.

The Kevlar 49/F161-188 system was selected because of a high level of interest in this material class by commercial aircraft companies for use on future airplanes. The selected system has been used to fabricate 727 engine cowls currently in service evaluation.

Standard Boeing procedures were used to process the materials so that the resulting specimens would have characteristics representative of manufactured commercial aircraft structures.

5.2 MATERIAL PROCESSING

All specimen fabrication processes were conducted with two goals. First, it was desired that the deployed specimens represent production quality, and second, batch-to-batch and process-variable effects were minimized.

Materials were purchased and controlled to existing Boeing material specifications or modified versions of existing specifications. The T300/5208 system was purchased to a Boeing material specification for epoxy preimpregnated graphite tapes cured at 177°C (350°F). The T300/5209 system and the AS-1/3501-6 systems were purchased to a slightly

modified version of the same specification. The primary changes for the 5209 system included a revised cure cycle and a reduced temperature for elevated temperature property requirements. Changes for the AS-1/3501-6 system were limited to minor changes in some mechanical property requirements. Finally, the Kevlar 49/F161-188 system was purchased to a Boeing material specification for aramid fabrics preimpregnated with 177°C (350°F) cure epoxy resin.

Receiving inspection and process control tests were conducted, and their results were part of the baseline material characterization. Receiving inspection test results for all materials and batches used on this contract can be found in references 6, 7, 13, and 14.

Once accepted, the material systems were processed according to existing process specifications or slightly modified versions of existing specifications. The modifications, when required, were made for the same reasons discussed in section 5.1. No postcuring was used. The cure cycle for the 177°C (350°F) cure graphite systems is shown in Figure 3. The cure cycle for T300/5209 is shown in Figure 4. The cure cycle for the Kevlar is shown in Figure 5.

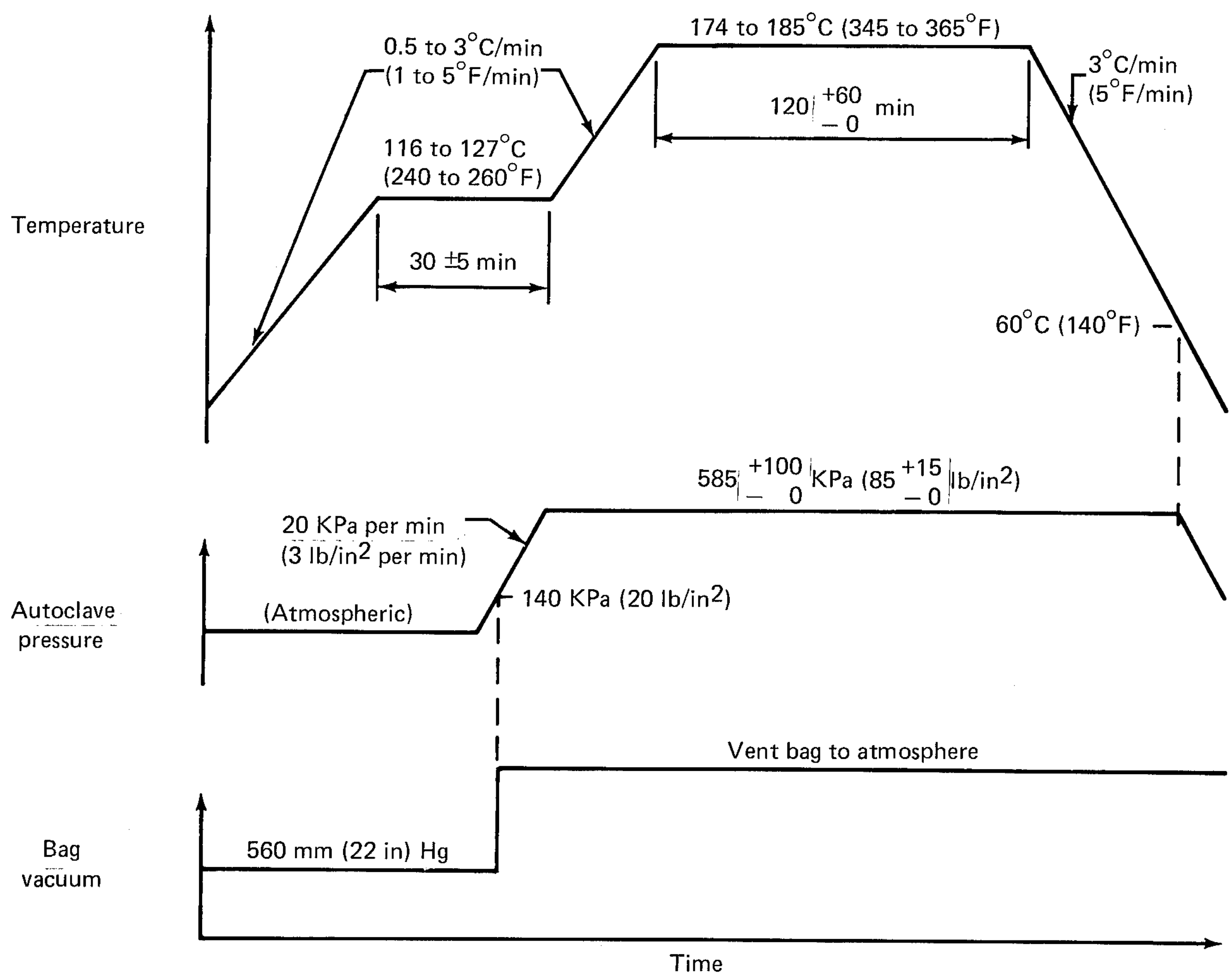


Figure 3. Cure Cycle for 177°C (350°F) Graphite-Epoxy Laminates

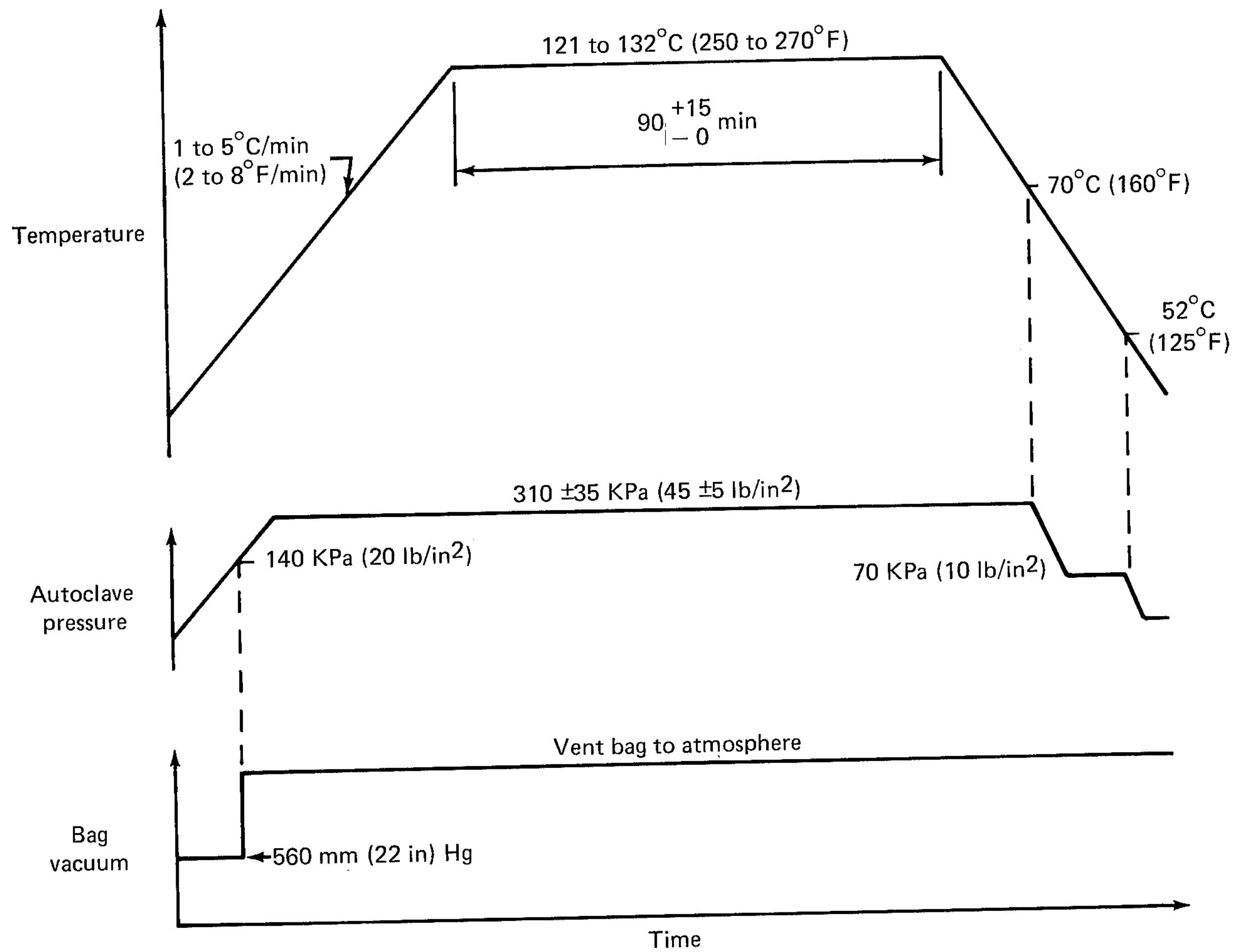


Figure 4. Cure Cycle for 121°C (250°F) Graphite-Epoxy Laminates

To minimize material and process variables, all prepreg for a specific material system was procured from a single batch. Specimens also were cut from large, wide-area laminates. As an example, the 2654 specimens required for the T300/5209 system were machined from only 10 laminates. One exception to the single batch rule occurred with the AS-1/3501-6 system where a machining error caused a shortage of compression specimens and required purchase of a quantity of material from a second batch. The compression specimens from the second batch of material were distributed throughout long-term deployment and were traced to permit a limited batch-to-batch evaluation.

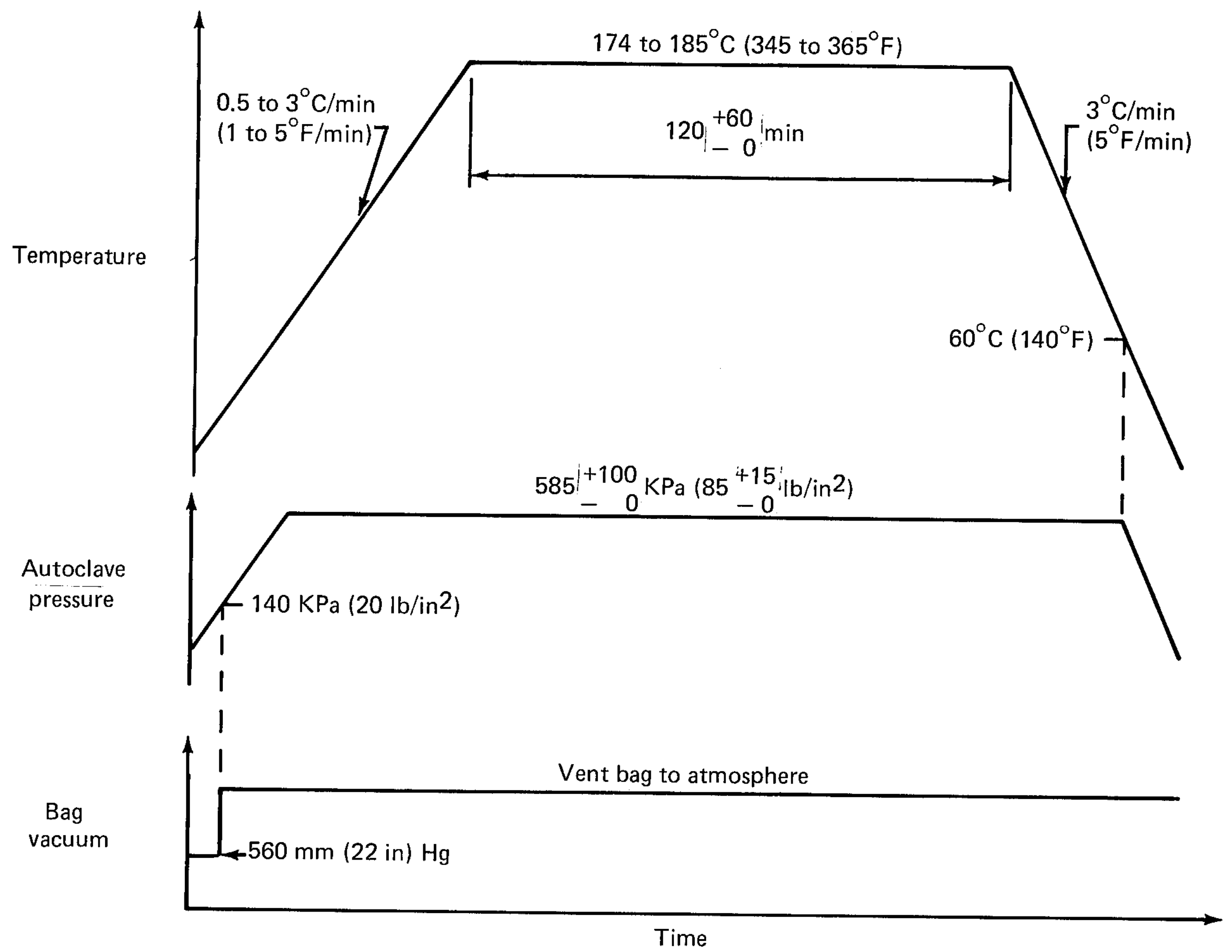


Figure 5. Cure Cycle for 177°C (350°F) Kevlar Laminates

6.0 TEST SPECIMENS

The mechanical, physical, and chemical changes in five different advanced composite material systems will be evaluated. Most physical and chemical property measurements are being made on mechanical property test specimens.

6.1 BASIC SPECIMENS

Four different mechanical test specimens were selected for evaluation and are found in all three tasks. They include tension, compression, short beam interlaminar shear, and flexure. These specimens will provide the required link between the long-term exposure data and the accelerated laboratory testing. The rationale for selecting these specimens is:

- Unidirectional short beam shear provides an inexpensive test to determine relative change of matrix properties, is an industry standard test, and is ideal for external flight exposure because of its small size.

- The crossplied flexure specimen also can be made small and, therefore, is well suited to external flight exposure. The 0 surface plies dominate the specimen strength, making the specimen sensitive to surface degradation. This configuration lends itself to plotting a load-deflection curve during test, thereby providing some measure of stiffness change.

- The ± 45-deg tension specimens produce matrix-critical data. The specimen has been used as an industry standard. This configuration also lends itself to being stressed during exposure.

- The unidirectional compression specimen provides a surface-sensitive matrix-critical specimen. Evidence suggests that this configuration will be the most discriminating of the four (ref. 4).

A Kevlar test specimen evaluation program was conducted to determine the best Kevlar test specimen configurations. Results of this program can be found in Reference 12.

Engineering drawings of all specimen geometrics appear in references 5, 6, and 13. The four basic test specimens are shown in Figure 6.

6.2 ADDITIONAL LABORATORY SPECIMENS

In addition to the four basic specimens, additional laminates of tension and compression specimens were added to the Task III accelerated laboratory test matrix. These specimens are:

Specimen Configuration	Laminate Layup
Compression	
Quasi-isotropic	$[\pm 45/0/90]_{3s}$
90 deg	$[90]_{20}$
Tension	
0 deg	$[0]_8$
Quasi-isotropic	$[\pm 45/0/90]_s$
90 deg	$[90]_{20}$

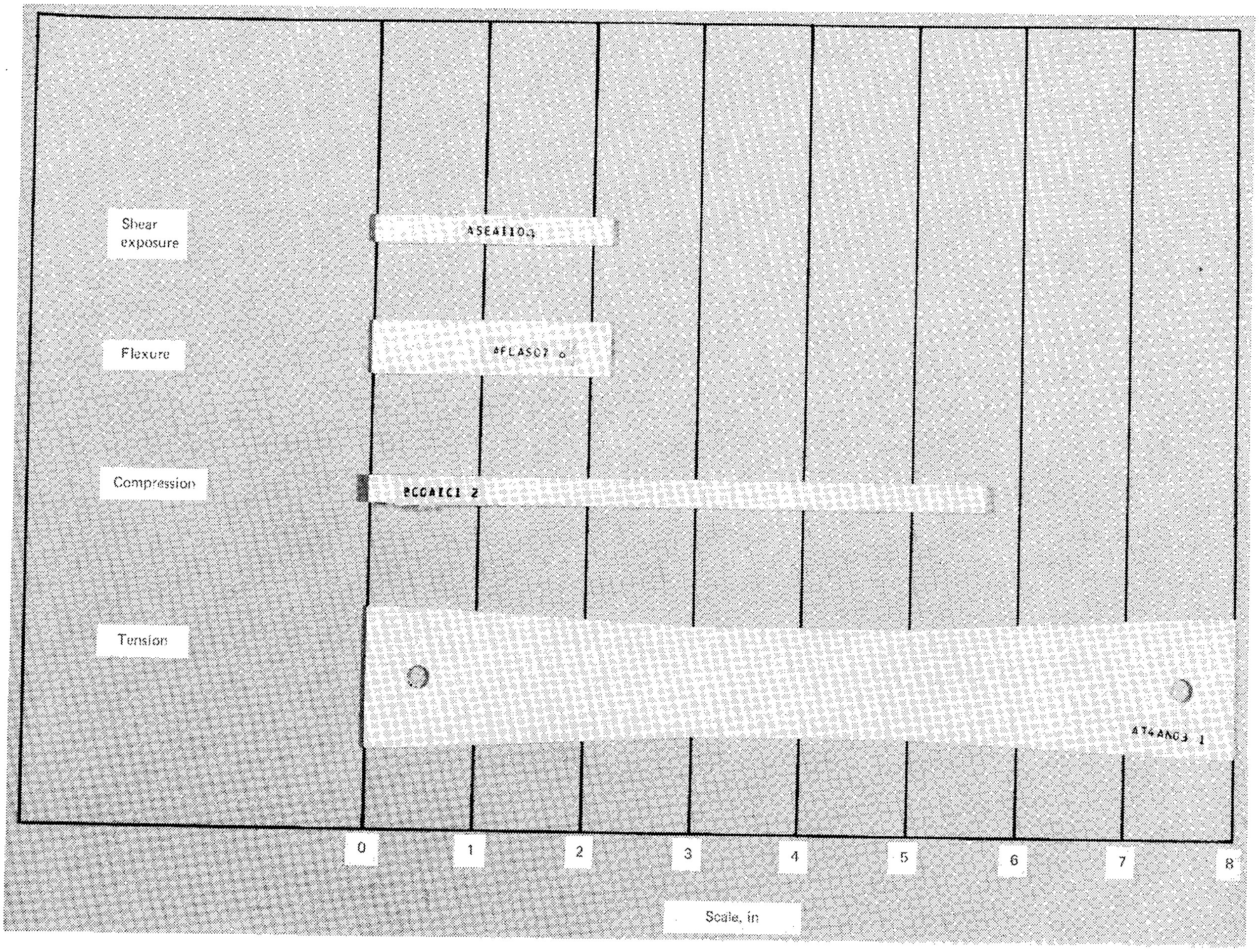


Figure 6. Basic Test Specimens—Painted

Specimens made from neat resin castings and specimens intended to evaluate the behavior of the paint film used in the long-term testing also were fabricated for Task III.

The unidirectional laminate specimens were added to more fully characterize the material systems. The quasi-isotropic specimens were included to test the performance of the materials in this laminate.

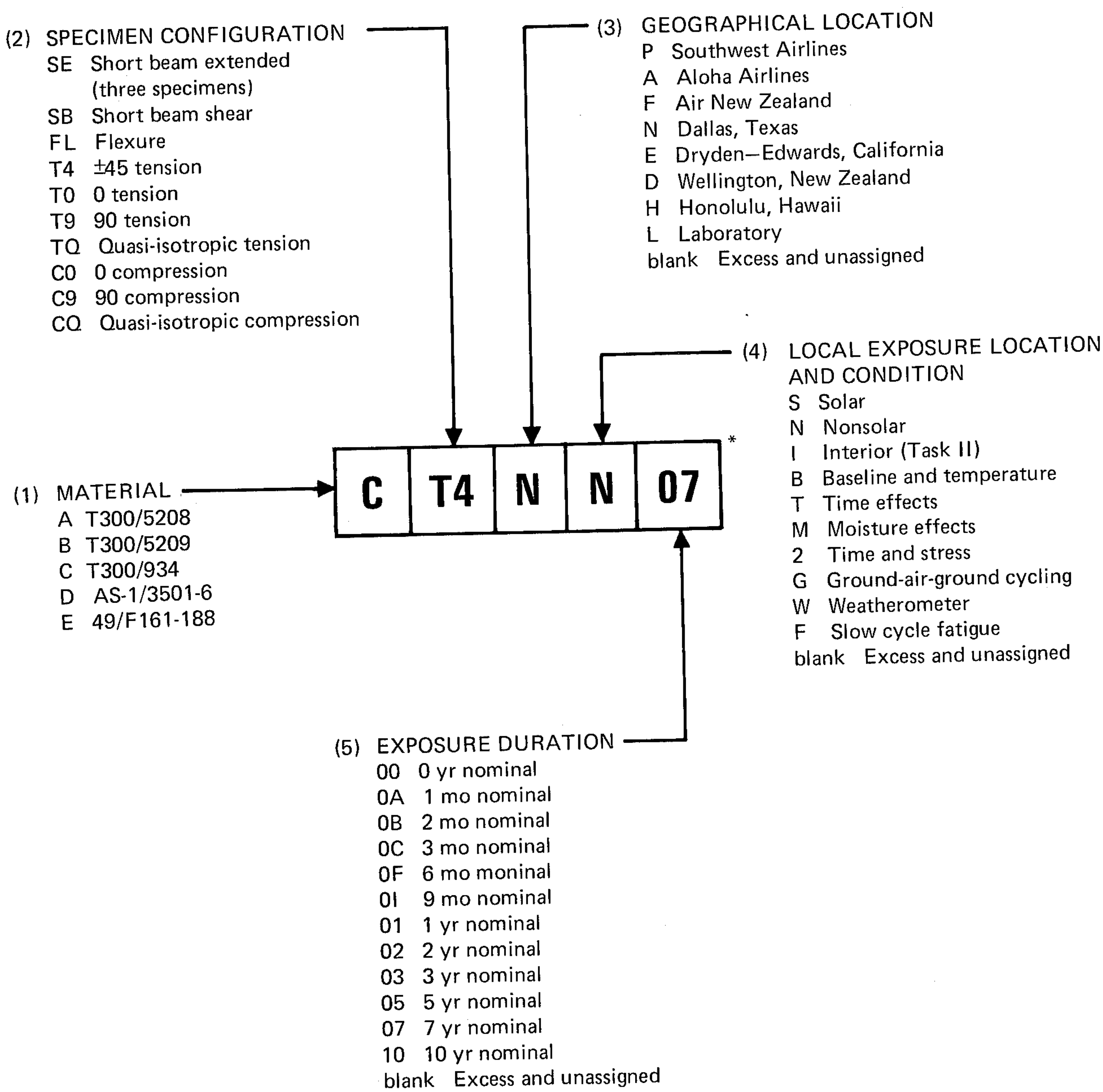
6.3 PAINT SCHEME

Composite structures in service will probably require a coating to provide protection from ultraviolet (UV) radiation that degrades matrix material at the surface. All the long-term ground and flight specimens and half of the specimens in the weatherometer environmental exposure chamber were painted similarly to the NASA Aircraft Energy Efficient (ACEE) program structures. The complete coating consists of one coat of primer and one coat of gloss enamel. The gloss enamel is a polyurethane exterior protective coating. The primer is corrosion resistant and compatible with the gloss enamel. Most of the laboratory-exposed specimens were not painted because they experienced insignificant UV radiation.

Although the paint affords UV protection to the matrix, other extraneous effects are introduced. For instance, the paint may absorb more moisture than the matrix material, making it difficult to measure the amount of moisture in the composite.

6.4 SPECIMEN NUMBERING SYSTEM

A specimen numbering system identifies the material system, specimen configuration, geographical exposure location, local exposure condition, and exposure duration. The seven-character alphanumeric identification scheme is summarized in Figure 7.



*Material 934—±45 tension, Dallas (ground rack), nonsolar, exposed for 7 years

Figure 7. Specimen Numbering System

Considerable attention was devoted to identifying and tracking specimens through weighing, measuring, painting, reweighing, exposure, and postexposure evaluation. It was decided that any method of identification capable of lasting through 10 years of exposure (e.g., vibro etch) would compromise the integrity of the test specimen or the paint film. A system involving stick-on labels was therefore devised. A computer program generated the specimen numbers in a format that could be printed onto adhesive-backed paper and cut up into individual labels. These labels were initially applied to the specimens at the same time as the graphite-only weight and dimensions were recorded. Fixtures were built to hold the specimens during the painting operation. These fixtures provided a space adjacent to each individual specimen where the label could be placed during painting. Once the paint had dried, the labels were returned to the adjacent specimen.

The computer program also generated the specimen numbers in a format that could be attached to standard 80-column computer program coding forms to create data sheets as shown in Figure 8. Spaces are provided for recording thickness, width, weight, and failure load measurements. There are four columns for weight measurements, the first for the unpainted specimen, the second for the painted specimen, the third for the exposed specimen after return to Boeing, and the fourth for the dried out specimen after exposure and return to Boeing. Not all specimens require data in all columns. The last column labeled "Remarks" is used for recording the test temperature. The completed data sheets are used to keypunch the data on computer cards for data storage and to facilitate data entry into computer files for analysis. Convenience required that data be recorded in U.S. customary units except for weights, which were recorded in grams.

6.5 SPECIMEN WEIGHTS

Individual specimen weights were measured at various points of exposure for most of the specimens assigned to long-term or accelerated laboratory exposure. Measurements were performed at the following phases of fabrication and exposure:

- Before painting and after storage in a drum under dry conditions--25 to 30% relative humidity (RH).
- After painting—all of the long-term exposure specimens were painted, but most of the accelerated laboratory specimens were left unpainted.
- After the environmental exposure—before mechanical testing.
- After dryout and before mechanical testing--most of the specimens were not dried prior to testing.

These measurements provide before/after exposure weight comparisons and the weight of the paint for the painted specimens. In addition, many laboratory specimen weights were tracked throughout exposure to provide details of the effects of exposure on moisture gain and erosive effects.

The weight change effects being measured include:

- Moisture absorption or desorption
- Foreign substances (dirt) attached to the surface
- Paint or material chipping
- Surface material erosion

NAS1-15148 DATA SHEET

SPECIMEN TYPE: ______
PREPARED BY: ______

SUPPLIER/MATERIAL: ______ GRADE/STYLE: ______ CATEGORY: ______ NO. OF PLIES: ______

SPECIMEN NUMBER	SERIAL NUMBER	LAMINATE THICKNESS (in)	LAMINATE WIDTH (in)	INITIAL DRY LAMINATE ONLY WEIGHT (gm)	INITIAL DRY SPEC. WEIGHT (gm)	EXPOSED SPECIMEN WEIGHT (gm)	FINAL DRY SPECIMEN WEIGHT (gm)	ULTIMATE FAILURE LOAD (lb)	REMARKS
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Figure 8. Specimen of Physical Property Data Sheet

In general, before/after exposure gross specimen weights may not be the best way to measure or track absorbed moisture in individual specimens, especially when they are subject to complex environmental conditions. For instance, weatherometer specimens suffer surface material erosion, and long-term flight specimens are subject to dirty conditions and rough handling. For these and similar exposure situations the best way to measure moisture content may be the dry-out procedure discussed in section 6.6. For some specific exposure conditions, such as conditions limited to relative humidity effects, gross specimen weights may be an appropriate way of tracking moisture absorption.

6.6 TEST PROCEDURES

The following paragraphs briefly describe the testing procedures for all specimen configurations associated with this contract. Strengths for each exposure situation and material are averaged, and overall strength is reported as a percentage of baseline strength. Baseline values are considered 100%; therefore, strengths reported above 100% are stronger than baseline, and strengths reported below 100% are weaker than baseline. Baseline testing was performed at three temperatures: room temperature, 40°C (120°F), and 82°C (180°F). Environmentally exposed specimens are tested at room temperature and 82°C (180°F). Specimens are soaked at temperature for 5 minutes. Elevated temperature testing is compared to baseline tests at that temperature.

Short Beam Shear--Short beam shear testing is used to measure an apparent shear strength in composite materials. The shear strength is useful in comparative testing but should not be used as design values. Testing was performed and strengths were calculated according to ASTM/ANSI standard D 2344-76. The specimens were loaded in three-point bending. The support span dimension is a function of specimen thickness. For graphite-fiber-reinforced materials, the span/thickness ratio is 4. The span/thickness ratio for Kevlar was determined in the specimen configuration testing described in Reference 12. Spans for all specimens of each material were determined as a group using average laminate thicknesses. The resulting values were:

Material	Span, mm (in)
T300/5208	9.9 (0.39)
T300/5209	10.4 (0.42)
T300/934	11.2 (0.44)
AS1/3501-6	10.3 (0.404)
49/F161-188	13.3 (0.524)

Specimens are all loaded to fracture in a Tinius-Olson mechanical testing machine at a crosshead deflection rate of 1.3 mm/min (0.1 in/min).

Flexure—The crossplied flexure specimens used in this contract are failure dominated by the surface 0 plies and therefore, are sensitive to surface effects. Testing was performed and strengths were calculated for extreme fiber stresses per ANSI/ASTM standard D790-71. Specimens are loaded to fracture in 3-point bending in a Tinius-Olson mechanical testing machine at a crosshead deflection rate of 2.5 mm/min (0.1 in/min).

Tension—All tension testing was performed in either an Instron or a Tinius-Olson testing machine at a crosshead rate of 2.5 mm/min (0.1 in/min). The specimens were held in ordinary mechanical grips with serrated jaws. In addition to the 0 specimens, the stressed ±45-deg were the only specimens with loading tabs; however, the jaw serrations do not adversely affect the testing quality of the untabbed specimens. Specimen response is monitored during each test with an extensometer, and a load/strain curve is plotted up to specimen fracture. Fracture load also is recorded for each test. Ultimate failure stress is calculated by dividing the failure load by the measured specimen cross-sectional area.

Compression—All compression testing on graphite-epoxy materials was performed using Celanese-style compression specimens and fixture. The IITRI compression fixture, which uses the same style specimens, also was considered. Several spare specimens were tested in each fixture to compare performance, and these results are discussed briefly in Reference 14. The Celanese fixture was selected because the Boeing test laboratories have access only to this fixture on a consistent basis.

The comparison tests showed that the load/deflection curves were more linear if a 13mm (0.5 in) gage block was inserted between the Celanese fixture jaws, and a load of 2200 N (500 lb) was applied. This preload is intended to align the jaws and set the jaw serrations into the specimen tab material without actually applying a load to the specimen.

Loading is performed at a crosshead deflection speed of 2.5 mm/min (0.1 in/min) or loading rate of 22 kN/min (5000 lb/min).

Specimen Dryout—Moisture Content—One shear exposure specimen from each long-term exposure condition and for each material is reserved for a dryout procedure at the end of the deployment duration. Upon return to Boeing, the specimens are weighed and the dryout specimens are placed in a 71°C (160°F) circulating air oven. The specimen weights are tracked until the specimens cease losing weight, a period usually lasting about 90 days. Once the specimens are dry they are divided into three short beam shear specimens each and tested in the usual manner.

The maximum weight loss incurred is assumed to be equal to the specimen moisture content at time of return. This value shows the moisture content for all specimens of a particular material and exposure situation. When compared with the other short beam shear specimen tests, the dryout specimen tests show the effect of moisture content on strength and stiffness response.

7.0 LONG-TERM EXPOSURE

7.1 TASK I—FLIGHT EXPOSURE PLAN

The plan for Task I exposure is shown in Figure 9. Tests and specimen configurations have been selected to provide maximum data for correlation among the three tasks and for integration into mathematical models. The matrix covers:

- Participating airlines
- Retrieval periods
- Exterior and interior exposure
- Material systems
- Specimen configurations
- Stress states
- Replicate specimens
- Residual test temperatures
- Solar and nonsolar exposure

Taking one basic interior or exterior specimen set unit at each exposure site on the aircraft, the matrix shows 98 specimens deployed on the aircraft exterior and 81 specimens deployed in the aircraft interior for each planned retrieval period. As each retrieval period arrives, one interior set and one exterior set would be removed and returned to Boeing for testing and evaluation. Initially, only the 1-, 2-, and 10-year flight exposure specimens were deployed. This kept the total number of aircraft involved to a minimum while keeping the total exposure duration within 10 years. When the 1-year flight exposure specimens are removed from the aircraft, they are replaced with 3-year exposure specimens. When the 2-year exposure specimens are removed, they are replaced with 7-year exposure specimens. When the 3-year exposure specimens are removed, they are replaced with the 5-year exposure specimens.

7.2 TASK II—GROUND EXPOSURE PLAN

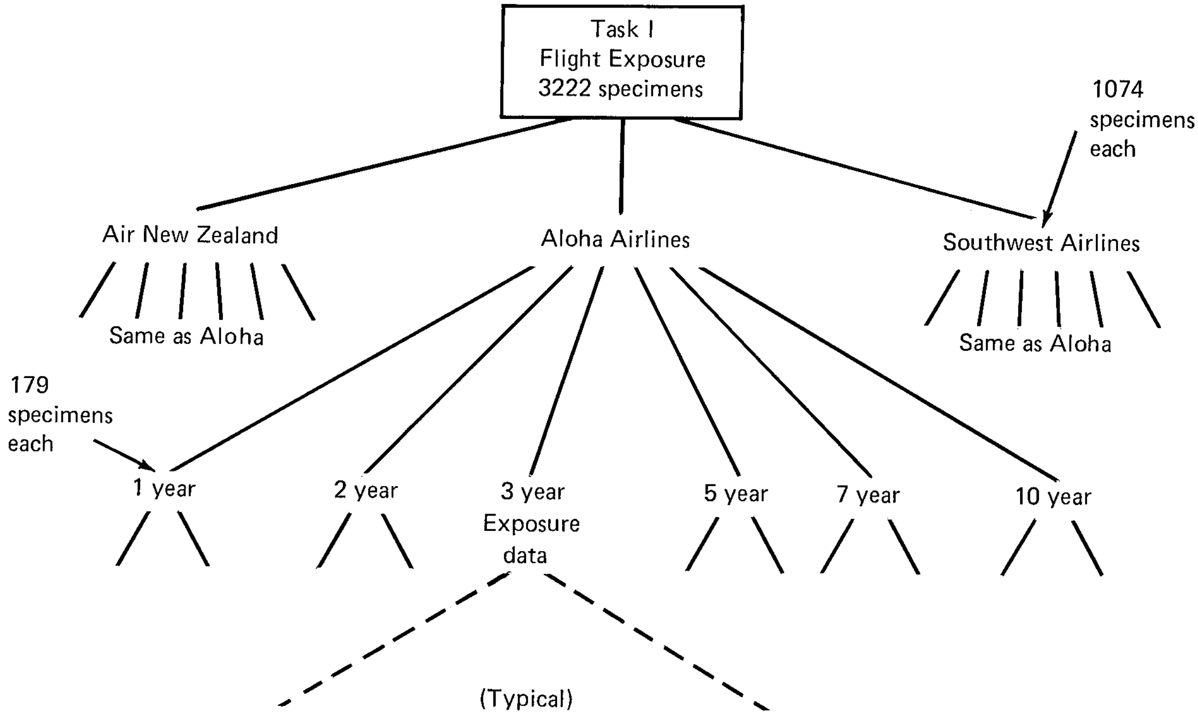
The exposure plan for Task II testing is shown in Figure 10. The matrix covers:

- Geographical exposure locations
- Retrieval periods
- Solar and nonsolar exposure
- Material systems
- Specimen configurations
- Stress states
- Three replicate specimens
- Residual test temperatures

At the end of each exposure period, the plan calls for 135 specimens to be retrieved and returned to Boeing. Of these, 63 are from the solar exposure face, and 72 are from the nonsolar face. All the ground rack specimens for T300/5208, T300/5209, and T300/934 at each location are deployed on one rack, and the specimens for AS-1/3501-6 and 49/F161-188 are deployed on a second rack.

7.3 AIRLINE AND SITE SELECTION

Exposure locations for Task I flight exposure and Task II ground exposure were based on several factors. Three of the four ground sites were predesignated as major operating



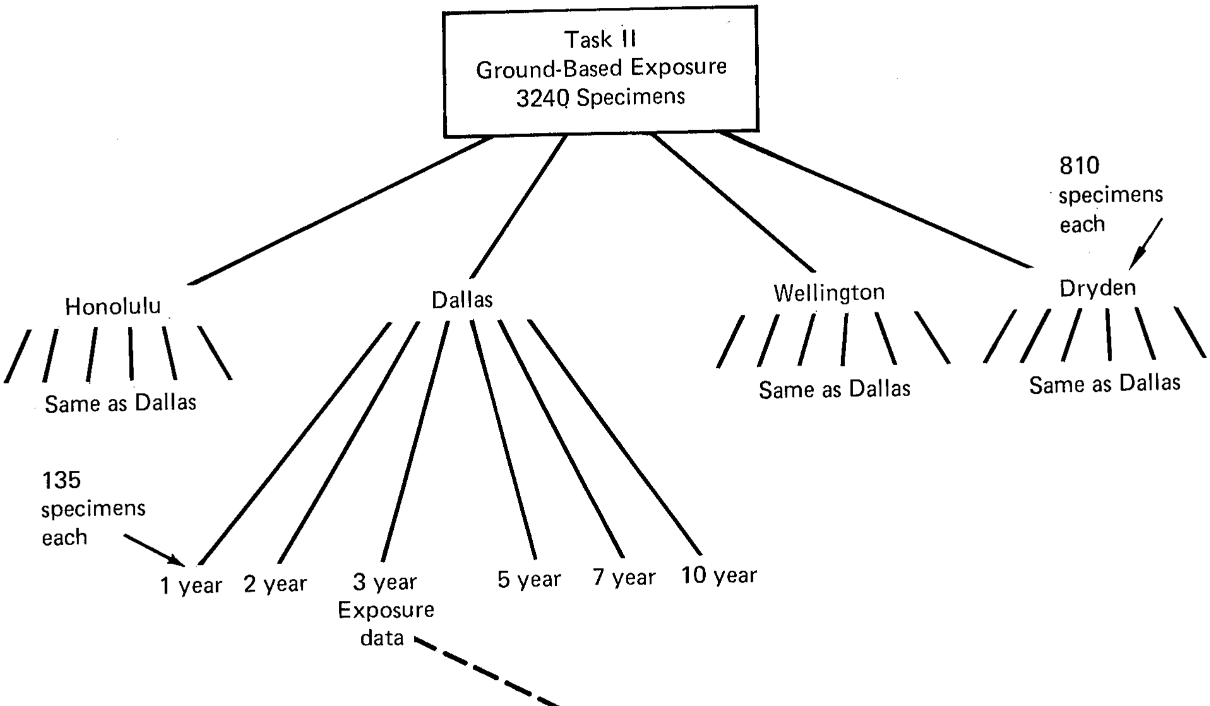
EXTERIOR OF AIRPLANE				
SPECIMEN SERIES	SPECIMEN CONFIGURATION	SOLAR EXPOSURE	RESIDUAL STRENGTH TEST TEMPERATURE °C (°F)	DRIED PRIOR TO TESTING
1	Short beam shear	Yes	21 (70)	
2		Yes	82 (180)	
3		Yes	82 (180)	Yes
4			21 (70)	
5			82 (180)	
6			82 (180)	Yes
7	Flexure	Yes	21 (70)	
8		Yes	82 (180)	
9			21 (70)	
10			82 (180)	
11	Tension	Yes	82 (180)	
12	Tension		82 (180)	

Note: (1) Matrix repeated for all five material systems, except that there are no tension specimens for T300/5209, AS-1/3501-6, 49/F161-188.
(2) Each specimen configuration contains three replicates except tension specimens which contain two replicates.

INTERIOR OF AIRPLANE		
SPECIMEN SERIES	SPECIMEN CONFIGURATION	RESIDUAL STRENGTH TEST TEMPERATURE °C (°F)
1	Short beam shear	21 (70)
2	Short beam shear	82 (180)
3	Flexure	21 (70)
4	Flexure	82 (180)
5	Compression	21 (70)
6	Compression	82 (180)
7	Tension (stressed)	82 (180)
8	Tension (unstressed)	21 (70)
9	Tension (unstressed)	82 (180)

Note: (1) Matrix repeated for all five material systems.
(2) Each specimen configuration contains three replicates.

Figure 9. Flight Exposure Test Matrix



GROUND EXPOSURE DATA, Xth YEAR				
SPECIMEN SERIES	SPECIMEN CONFIGURATION	SOLAR EXPOSURE	RESIDUAL STRENGTH TEST TEMPERATURE °C (°F)	DRIED PRIOR TO TESTING
1	Short beam shear	Yes	21 (70)	
2		Yes	82 (180)	
3		Yes	82 (180)	Yes
4			21 (70)	
5			82 (180)	
6			82 (180)	Yes
7	Flexure	Yes	21 (70)	
8		Yes	82 (180)	
9			21 (70)	
10			82 (180)	
11	Compression		21 (70)	
12	Compression		82 (180)	
13	Tension (stressed)		82 (180)	
14	Tension (unstressed)	Yes	21 (70)	
15	Tension (unstressed)	Yes	82 (180)	

Note: (1) Matrix repeated for all five material systems.
(2) Each specimen configuration contains three replicates.

Figure 10. Ground Exposure Test Matrix

terminals of the selected Task I airlines so that selection criteria was heavily biased towards the Task I requirements.

Individual factors that played a part in the selection process included:

- Airline route structure
- Airline fleet size and willingness to support the program
- General climatic factors within the area
- Airline, aircraft utilization
- Political climate of the area

No attempt was made to seek out arbitrary worst case environments. Instead the selected sites represent a good cross section of the kind of environments that commercial transport structure could be expected to see.

A summary of the selected long-term exposure sites is shown in Table 1. The selection criteria favored the use of regional airline carriers operating in a known climatic region. All three of the selected airlines had the required fleet size (six-airplane minimum) and expressed an interest in the program. Air New Zealand and Aloha Airlines have provided excellent support on similar programs in the past.

Table 1. Flight and Ground Exposure—Locations and Participants

TASK I—FLIGHT EXPOSURE	TASK II—GROUND EXPOSURE	
AIRLINES	RACK LOCATION	COMMENT
Air New Zealand Ltd. Aloha Airlines Southwest Airlines	Wellington, New Zealand Honolulu, Hawaii Dallas, Texas NASA-Dryden Flight Research Center, California	Air New Zealand Heaquarters Aloha Airlines Headquarters Southwest Airlines Headquarters

The general climatic factors within the airline route structure are summarized in Figure 11. Honolulu's warm, moist conditions are typical of tropical climates, which provide a harsh environment for conventional aircraft structure and are considered a potentially severe condition for moisture absorption in composites. There is little variation in temperature or relative humidity throughout the year.

Wellington will provide a cooler but more moist environment than Honolulu. Coupled with less solar heating, it is expected that the Wellington specimens, on the average, will contain more moisture than any of the other ground rack specimens.

Historical climate data for Dallas shows moderate and fairly constant relative humidity throughout the year but an extreme range of temperatures.

The fourth ground exposure site is the NASA-Dryden Flight Research Center at Edwards Air Force Base, California. This site represents arid to semiarid, desert-like regions and shows a large, seasonal variation ranging from cool and moist to very hot and dry. Based on monthly averages, it never gets as wet as Honolulu. It can be expected that the Honolulu specimens will absorb moisture to some equilibrium level and then change relatively little thereafter. The Dryden specimens, on the other hand, should undergo an annual absorption/desorption cycle for their entire exposure duration. The residual strength tests will assist in determining the relative severity of these two kinds of exposure.

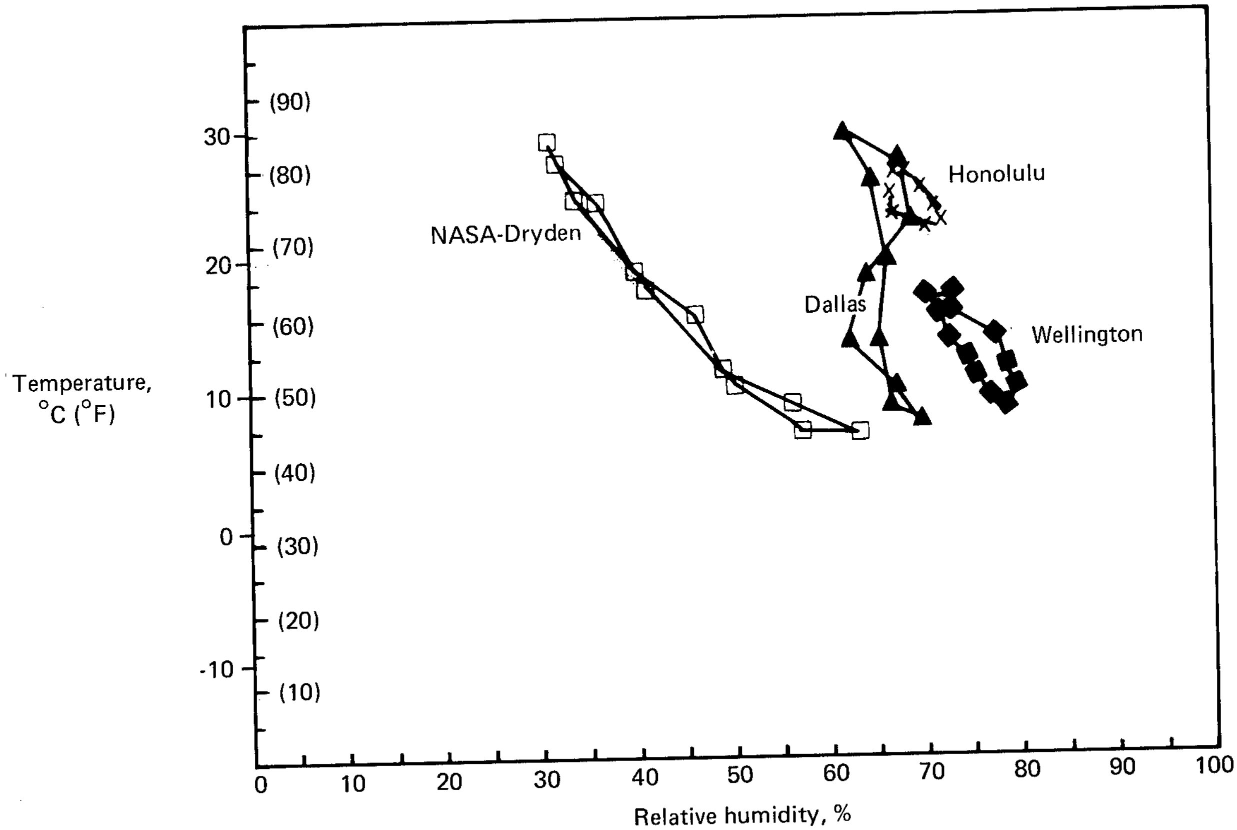


Figure 11. Ground Rack Climatic Data

The airline aircraft utilization history also played a part in the selection process. Typical flight profiles for the three selected airlines are shown in Figure 12.

Aloha Airlines, which provided a unique flight environment, represents one extreme of a flight-usage spectrum. Flights are generally only during daylight hours and are flown in the area bounded by the Hawaiian Islands. Their hours-per-day utilization rate is relatively low, but because of an extremely short flight length, they accumulate numerous GAG cycles.

Air New Zealand operates 737's in a maritime environment, and all airfields either have oversea approaches and departures or are located quite close to the coast. Flights have a greater variation in range than Aloha Airlines, have longer average flight durations, and fly at higher average altitudes.

Southwest Airlines, on the other hand, operates in a relatively arid environment. Flight range and duration is between that of Air New Zealand and Aloha Airlines.

7.4 TEST SPECIMEN HOLDING FIXTURES

Because of the numerous small specimens involved in the program, fixtures were designed to hold them in groups. This allowed group deployment and simplified identification and tracking. Short beam shear and flexure specimens were housed in the fixture shown in Figure 13. This fixture was designed to hold up to six flexure specimens and up to three shear exposure (nine short beam shear) specimens. Compression specimens were housed as groups of six in a similar fixture shown in Figure 14. The production drawing for both fixtures is shown in Appendix B of Reference 7.

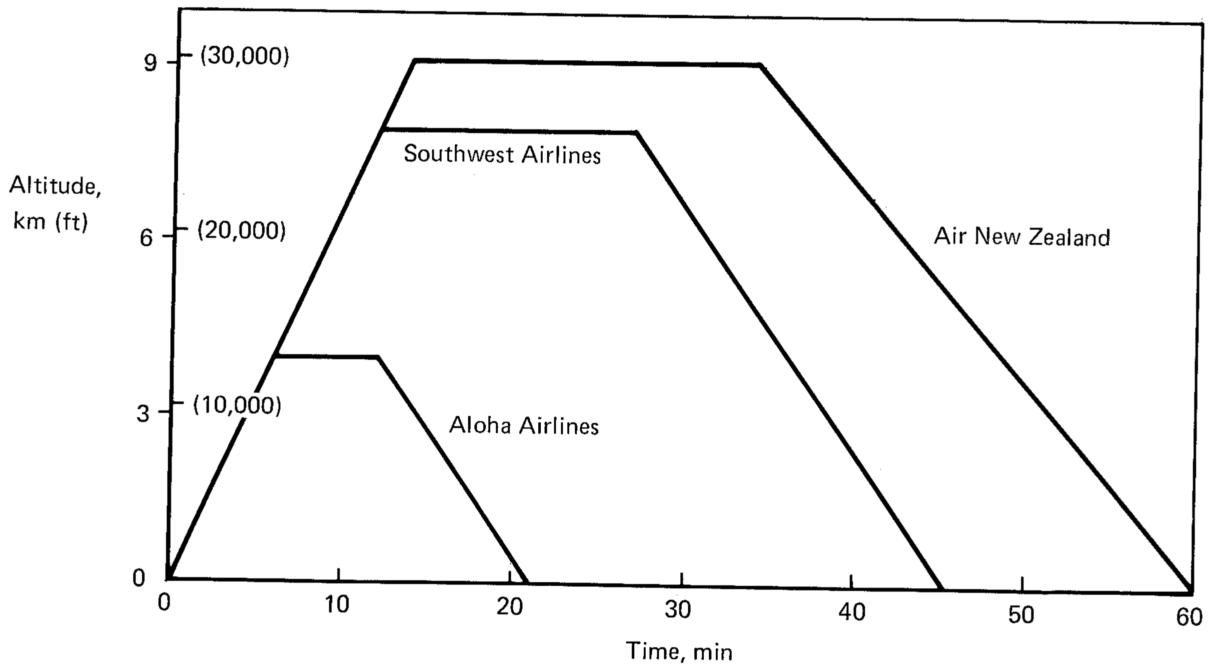


Figure 12. Typical Flight Profiles

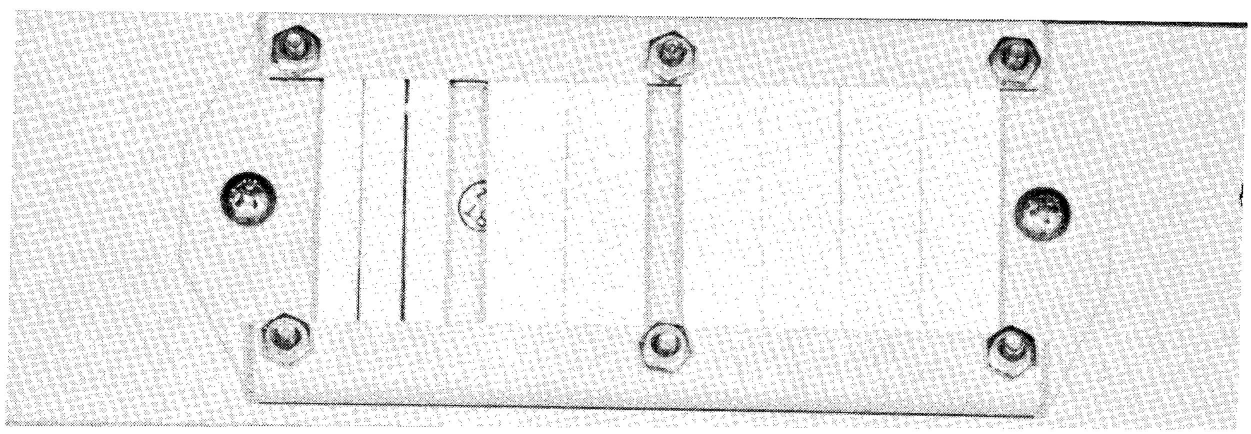


Figure 13. Short Beam Shear and Flexure Specimen Holding Fixture

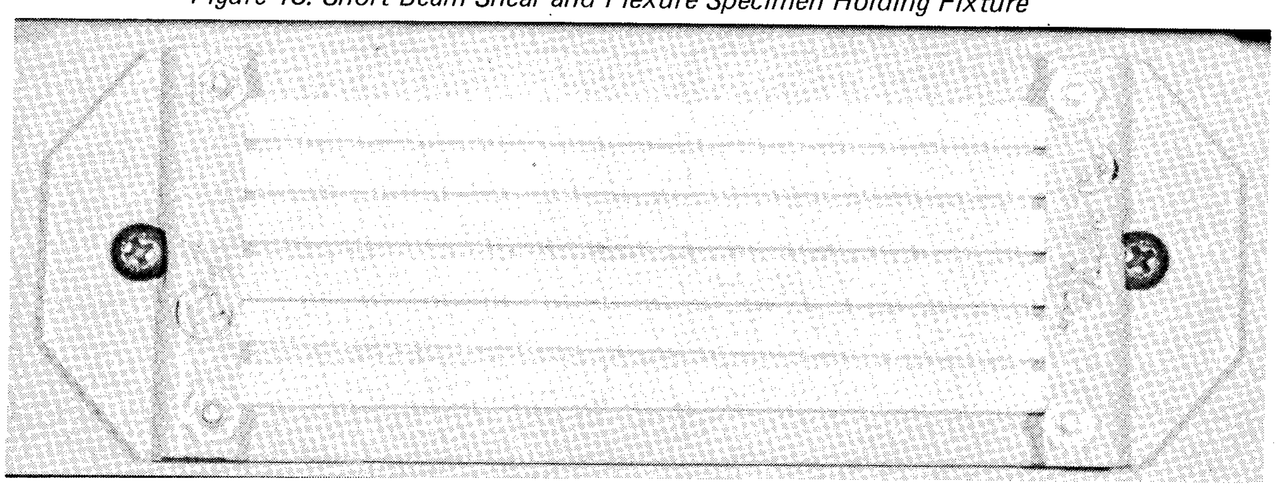


Figure 14. Compression Specimen Holding Fixture

The holding fixture for stressed tension specimens was designed to minimize size and weight while maintaining a sustained stress through a large variation in temperature. A cutaway of the completed fixture is shown in Figure 15. It consists of a ventilated titanium tube, with its characteristically low coefficient of thermal expansion, and a custom aluminum clevis that compensated for the near zero thermal expansion of the graphite test specimen. The length of the tube and the clevis were calculated so that the thermal expansion of the tube just equaled the thermal expansion of the specimen plus the aluminum clevis. Load is applied with the aid of a Bellville spring washer located just outside the end cap. The production drawing for this fixture was presented in Reference 7. The stressed tension specimens are loaded with a deadweight load procedure that accounts for springback in the test fixture. A target load of 1100 N (250 lb) was established to provide a reasonable stress level for determining differentiation with the unstressed specimens. A complete development of the procedure used to achieve this constant load is given in Reference 8.

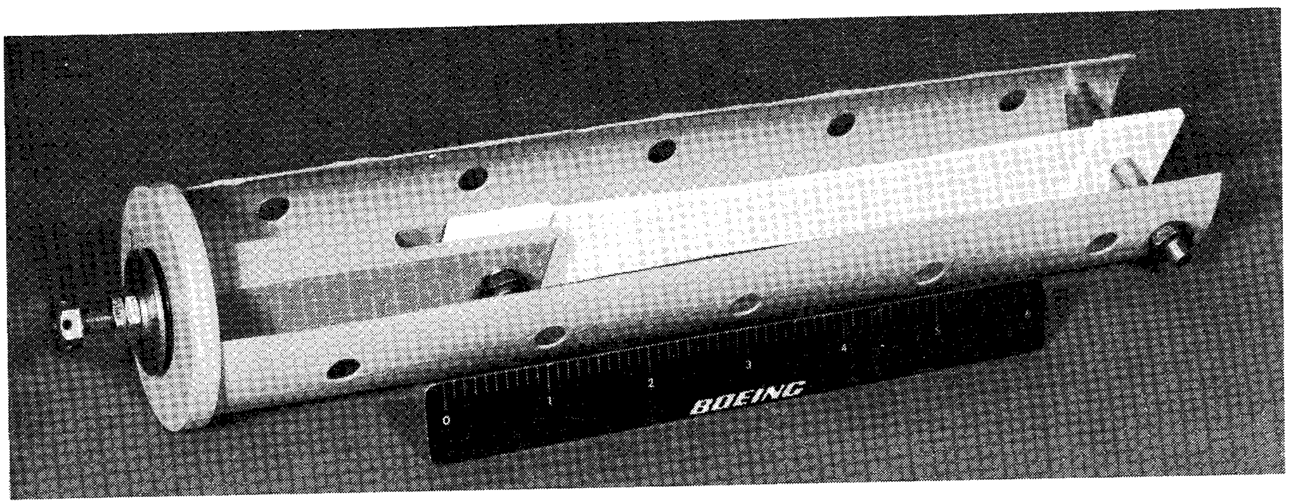


Figure 15. Cutaway of Stressed Tension Specimen Fixture

7.5 AIRCRAFT SPECIMEN DEPLOYMENT

Two specimen deployment locations were selected on the Boeing model 737 aircraft. These included the flap track fairing tailcone for exterior aircraft exposure and section 48 of the fuselage for interior aircraft exposure. The general location of these areas is shown in Figure 16. The tailcone of the flap track fairing offered several advantages for generating actual flight service environmental data on the exterior of an aircraft. Because it is aft of the wing, trailing-edge aerodynamic problems were minimized. The tailcone is held to the aircraft with 16 bolts, and no alterations were necessary in the existing aircraft structure. Once in place, it is readily accessible for inspection. Finally, mounting specimens on the upper and lower surfaces permitted examination of the effect of solar heating and UV radiation.

Two different modified flap track fairing tailcones were designed. The first version carries three of the short beam shear/flexure test specimen holding fixtures on the upper surface and three additional fixtures on the lower surface. The fixtures were attached to the tailcone with bolts and floating nutplates. A second tailcone was designed to hold four tension specimens on the upper surface and four more on the lower surface. Because the tailcones are essentially conical, it was possible to position the specimens along radial lines and, with a slight amount of shimming, ensure that they lay flat (unstressed) during

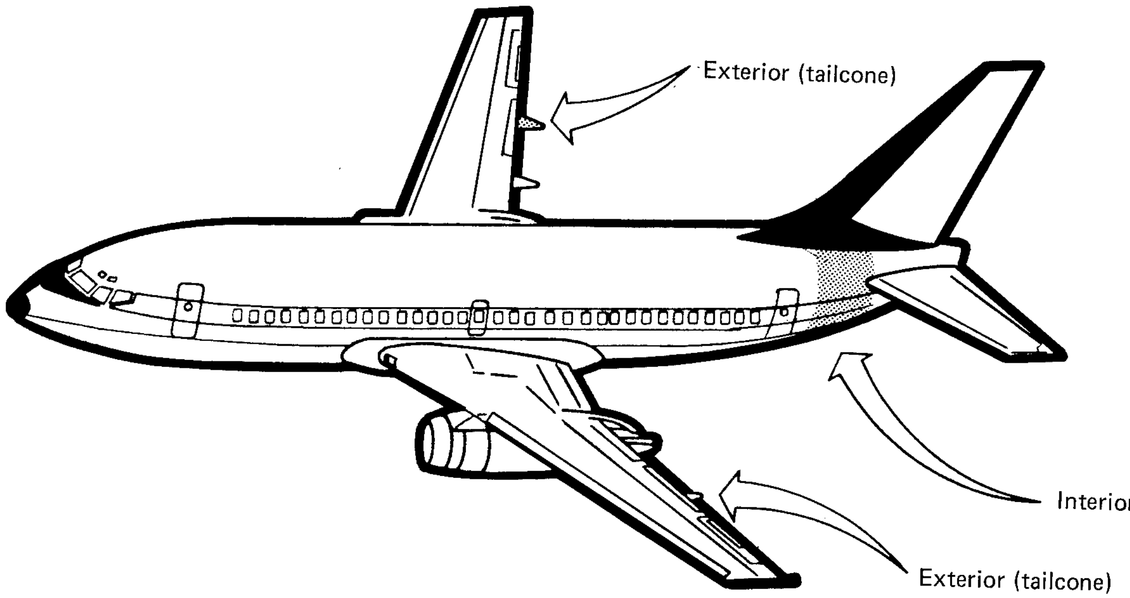


Figure 16. Flight Exposure Locations—Boeing 737

exposure. Again bolts and floating nutplates were used to attach the specimens to the tailcone.

The tailcones, specimens, and holding fixtures were assembled at Boeing and sent to the airlines, ready for installation. This minimized the downtime and installation time required of the airlines. The two modified tailcones are shown in Figures 17 and 18.

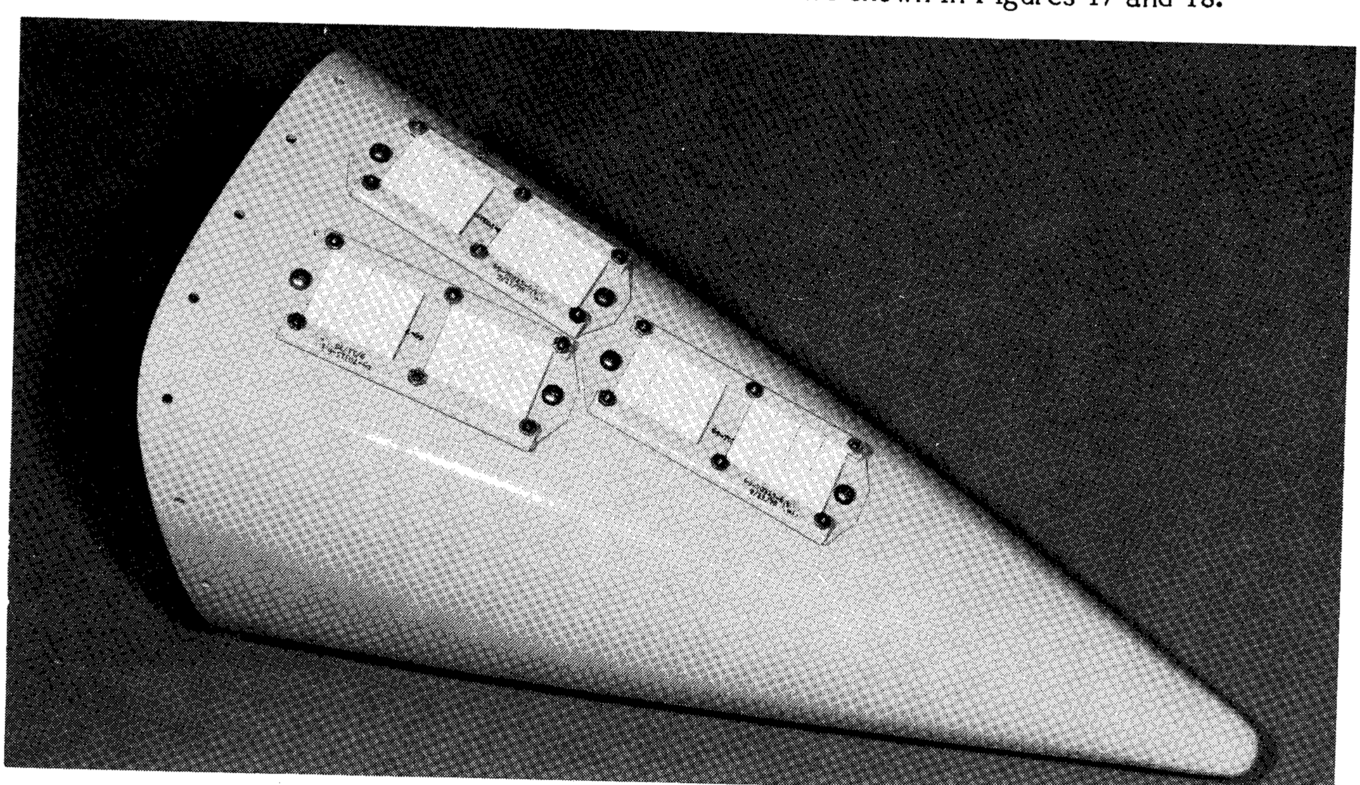


Figure 17. Tailcone With Shear and Flexure Specimen Fixtures Attached

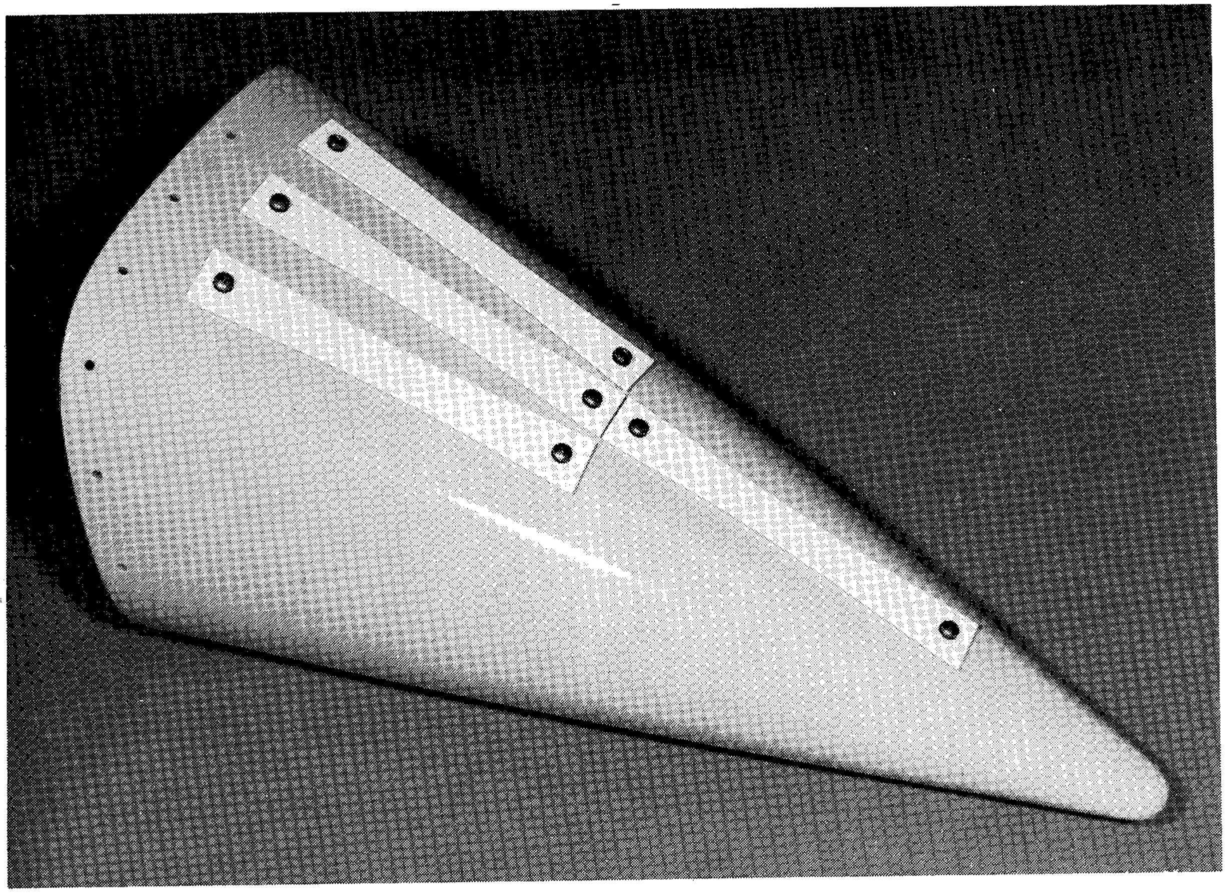


Figure 18. Tailcone With ±45 Tension Specimens Attached

The second area selected for specimen exposure was section 48 of the Boeing model 737 fuselage. The location is aft of the pressure bulkhead and ahead of the auxiliary power unit firewall. The specimens feel the ambient temperature and relative humidity because of sizable openings through the side of body for the horizontal stabilizer. This region also provided the large geometry envelope necessary for stressed exposure testing.

Short beam shear, flexure, and the graphite-epoxy compression specimens were grouped in the specimen-holding fixtures described in section 7.4 and attached to the fuselage stringers. This was accomplished by adopting a nylon stringer clamp normally used in production to attach wiring bundles. Figures 19 and 20 show a mockup of the finished installation.

Figure 21 shows six tension specimens exposed on the interior of the aircraft. In this case, the nylon stringer clamps along with standard fasteners and phenolic washers were adequate, and no additional fixturing was required.

Stressed tension fixtures were attached to the fuselage stringers. The previously described nylon stringer clamp did not lend itself to this installation so a phenolic saddle was designed that would attach to the stringer without having to drill holes in the fixture tube. Figure 22 shows the complete installation in mockup form.

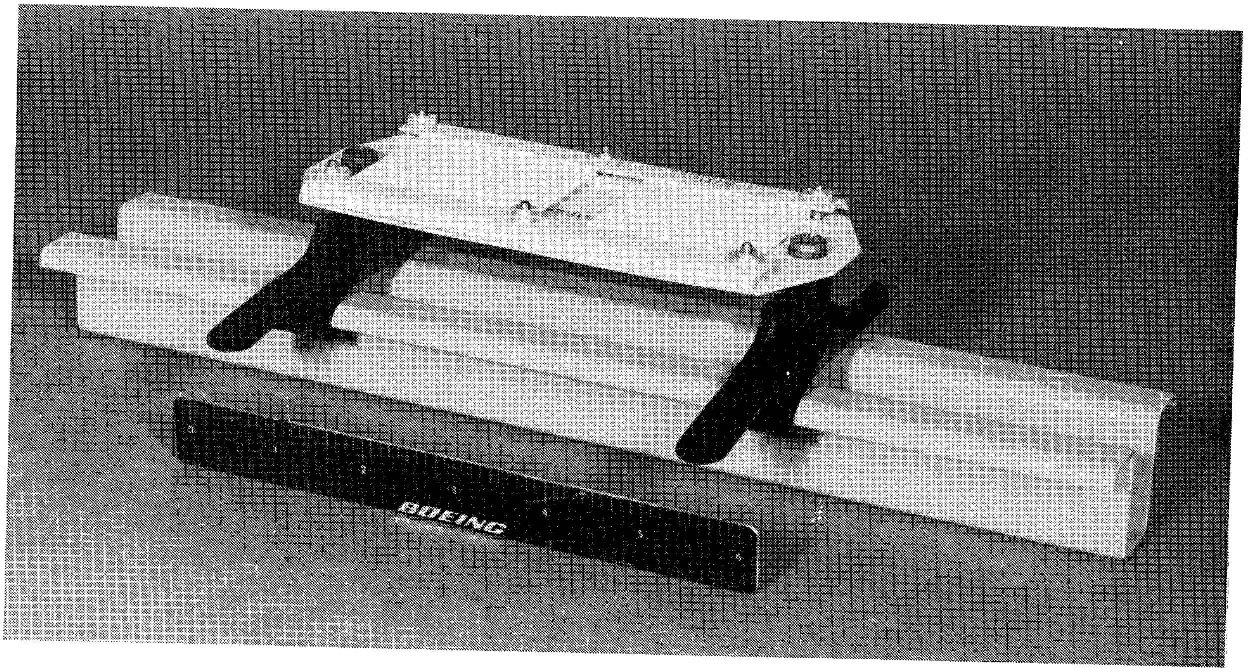


Figure 19. Interior Aircraft Shear and Flexure Specimen Fixture

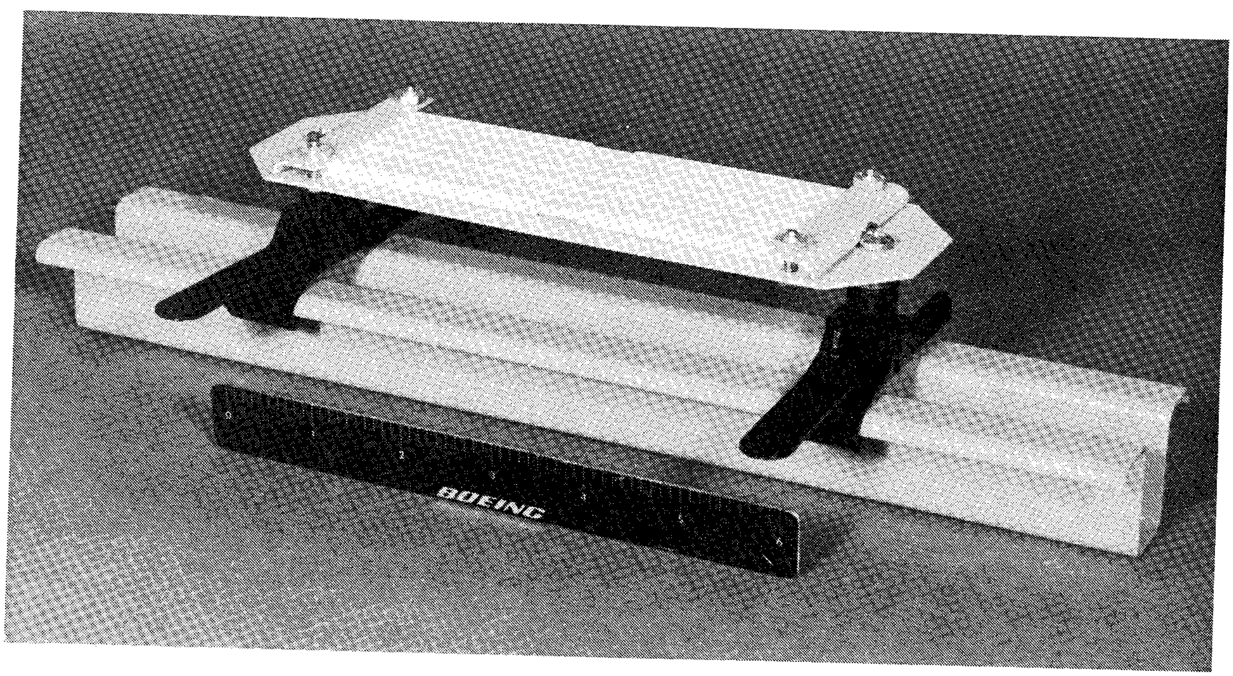


Figure 20. Interior Aircraft Compression Specimen Fixture

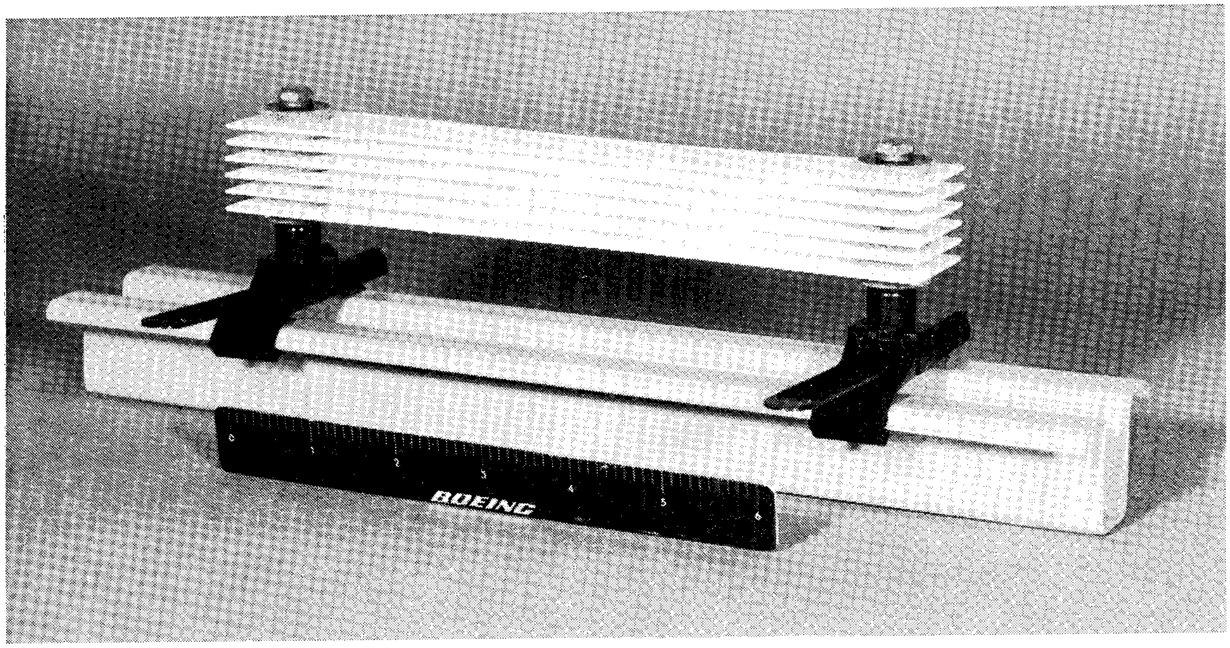


Figure 21. Interior Aircraft Tension Specimen Fixture

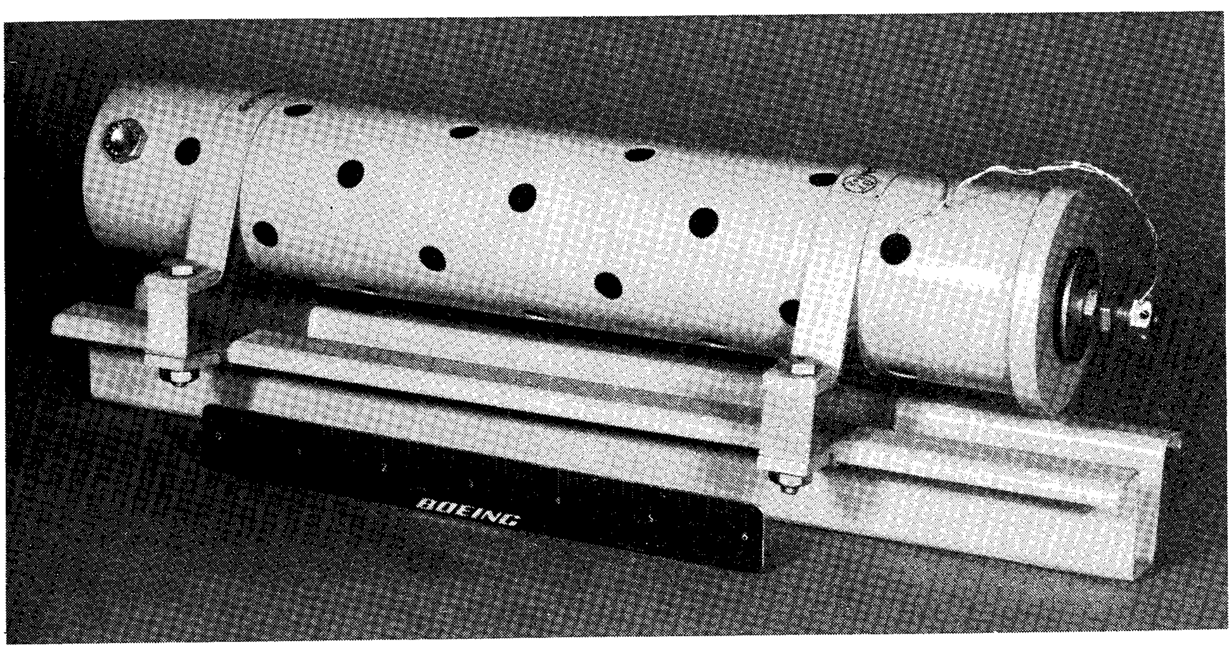


Figure 22. Interior Aircraft Stressed Tension Specimen Fixture

7.6 GROUND SPECIMEN DEPLOYMENT

A rack was designed to expose specimens to both solar conditions (all aspects of ambient environment including direct sunlight) and nonsolar conditions (all aspects of ambient environment except direct sunlight). Consideration was given to:

- Exposure area requirements for each retrieval station
- Maximum retrieval flexibility
- Shielding nonsolar specimens
- General simplicity for minimum cost
- Rack transportation and setup

The resultant rack design consisted of an aluminum mainframe and 36 insert panels. Each insert panel or exposure station was designed to hold all of the specimens of one material system for one exposure time to either solar or nonsolar exposure. The area requirement for solar or nonsolar exposure for each material system for each withdrawal time is approximately $0.9m^2$ ($1\ ft^2$).

The maximum possible number of retrieval stations per rack location is 72. This is based on a maximum of six materials, each retrieved a maximum of six withdrawal times, and each retrieval consisting of two stations (one solar and one nonsolar). A preliminary sizing showed that a 72-station rack would be unfeasible, but that a 36-station rack would be suitable.

The 36 exposure stations are housed on a triangular frame nominally 2.7m (9 ft) long by 0.6m (2 ft) high. The rack mainframe is primarily 6061 aluminum alloy with welded construction. This will provide the required stiffness for the lattice to which each exposure station will be attached.

The exposure stations or insert panels consist of 2024-T3 aluminum sheets that are drilled to receive the appropriate specimens and painted. They are attached to the mainframe with four quarter-turn quick-release fasteners. One insert panel design, shown in Figure 23, was used for exposure, and the design shown in Figure 24 was used for nonsolar exposure.

Nonsolar specimens were shielded from direct UV impingement with a slab of phenolic honeycomb core as shown in Figure 25. This design provided adequate air circulation and allowed precipitation to drain down the individual cells and on the specimens.

A completed rack is shown in Figure 26. The 18 solar exposure panels, complete with specimens, are shown on the front side. The honeycomb sunshield that protects the nonsolar specimens from direct exposure to the sun is visible on the back side.

7.7 LONG-TERM SPECIMEN TRACKING AND LOAD MAPS

Because it was impossible to maintain the identification tags on individual specimens, it was decided to track exposure history by the specimen-holding fixture. Each of the titanium fixtures, tailcones, and ground rack insert panels described in section 4 contains a permanent steel, stamped identification number. A series of load maps was prepared that identified specific specimens for each holding fixture. An example is shown in Figure 27. Once the test specimens are located in a fixture, the paper labels that had accompanied each specimen to that point are removed. When the fixture is returned following the desired exposure duration, individual specimens will be reidentified prior to disassembling the fixture. This will be done with a new set of labels or in ink.

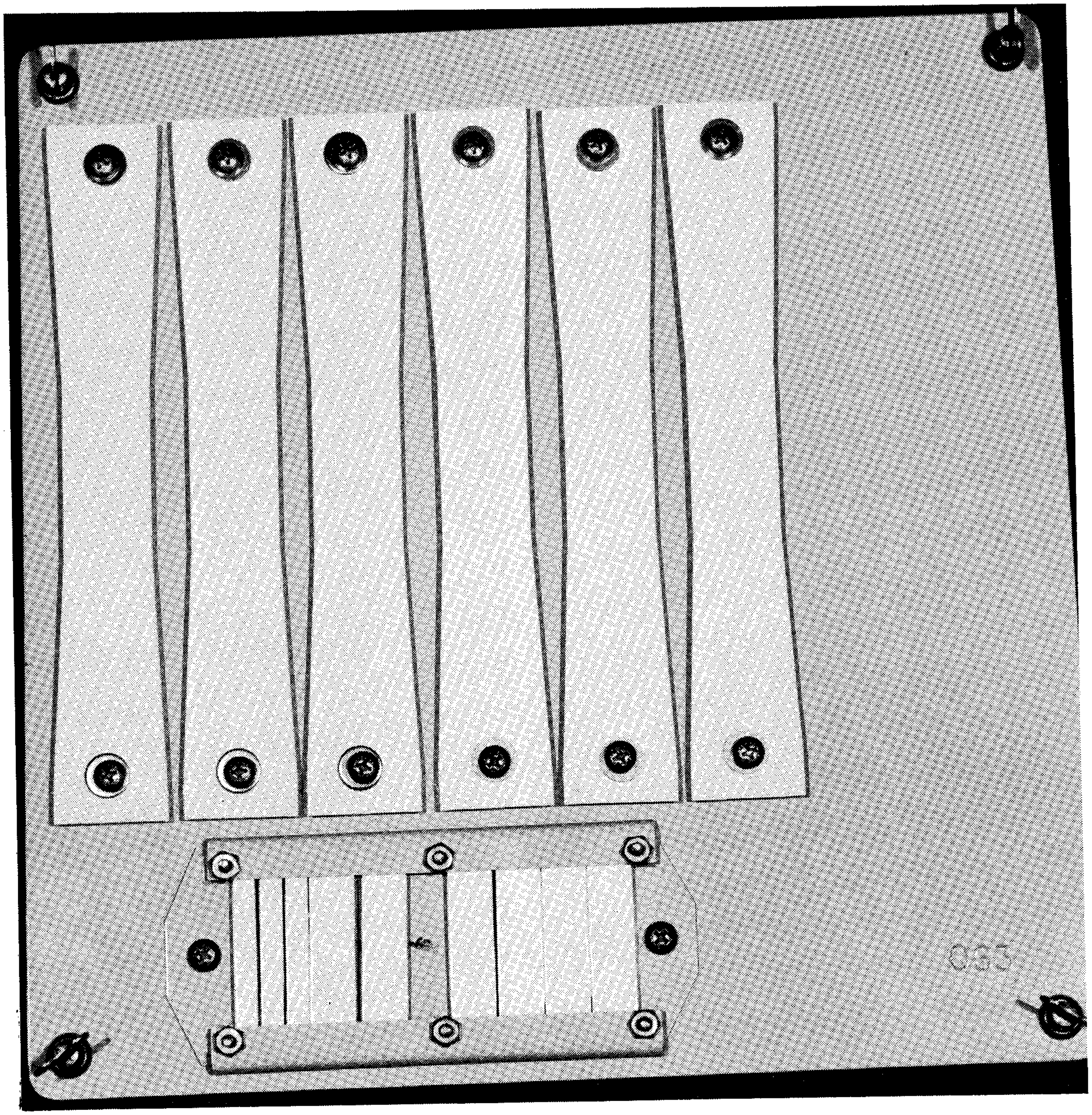


Figure 23. Solar Ground Exposure Insert Panel

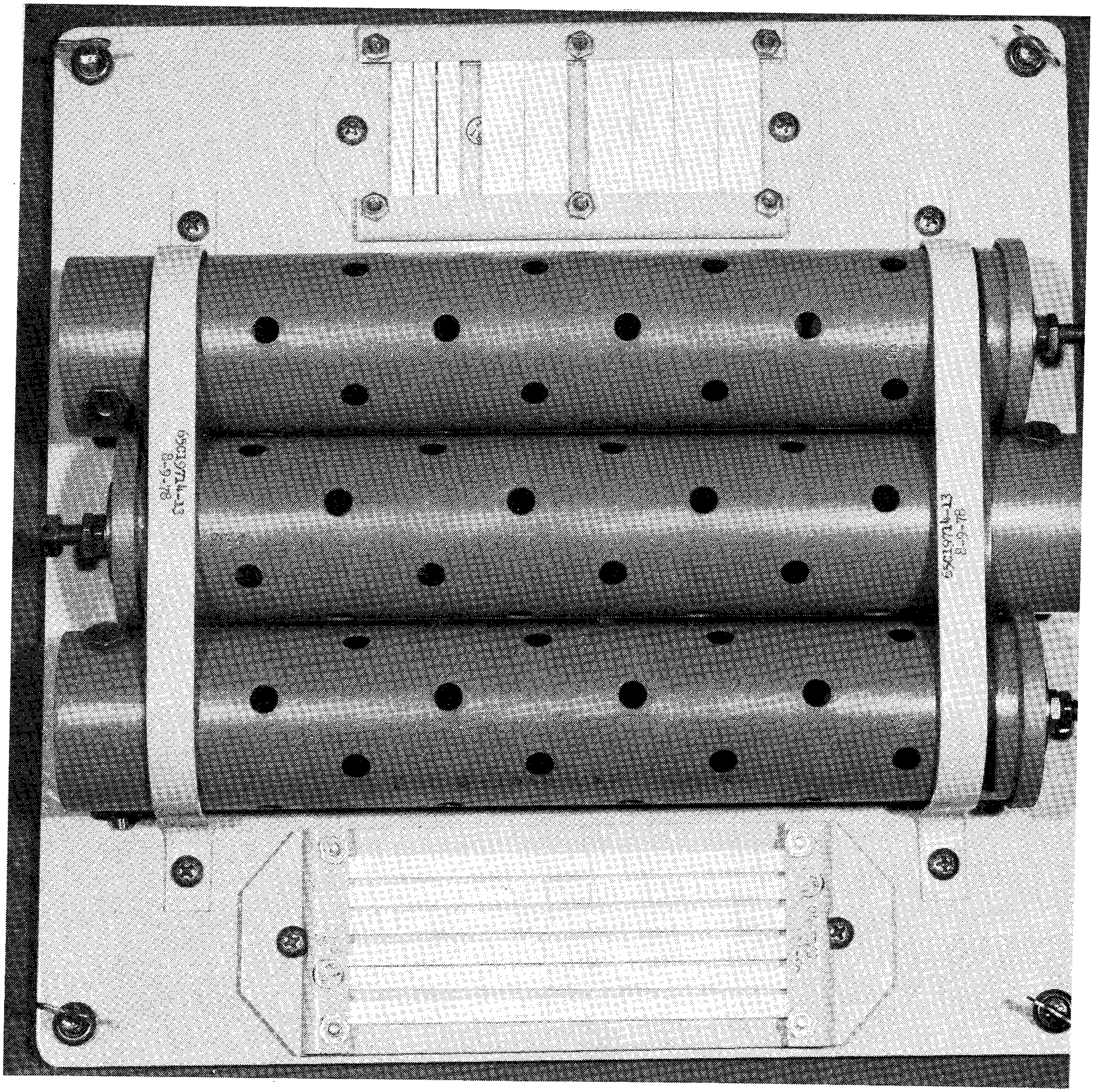


Figure 24. Nonsolar Ground Exposure Insert Panel

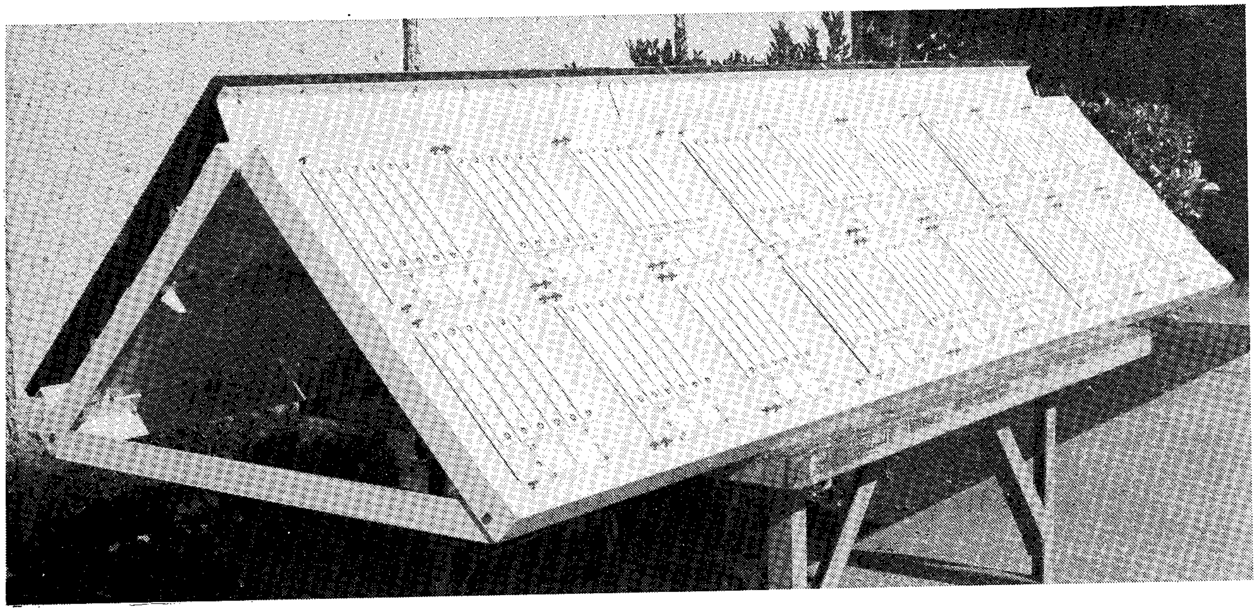


Figure 26. Ground Exposure Rack

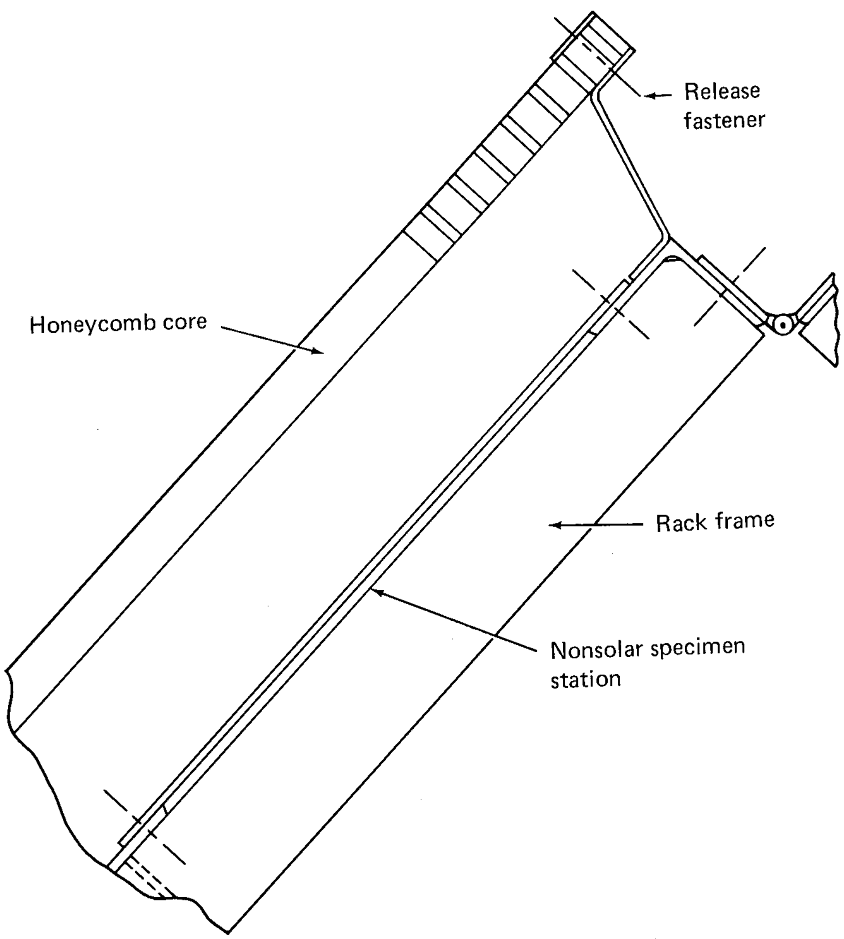


Figure 25. Honeycomb Sunshade Concept

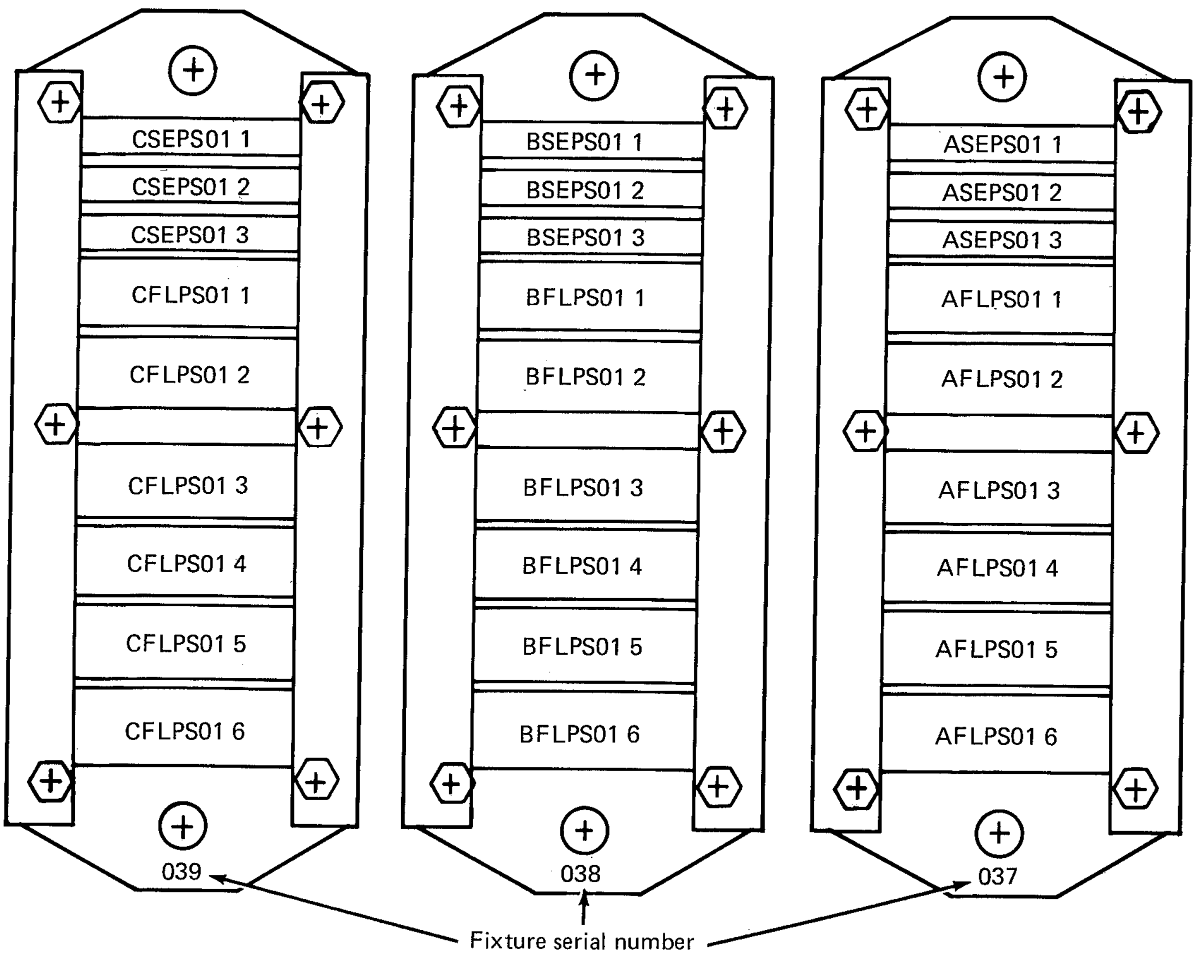


Figure 27. Sample Load Map

8.0 ACCELERATED LAB EXPOSURE

8.1 BASELINE AND EFFECT OF TEMPERATURE

To establish basic specimen mechanical properties of the five contract materials, baseline and effect-of-temperature testing was performed. Specimens included short beam shear, flexure, 0-, 90-, and ±45-deg tension, quasi-isotropic tension, 0- and 90-deg compression, and quasi-isotropic compression. Five replicate specimens of each configuration were tested at each of the three test temperatures. Table 2 gives a complete breakdown of specimens and testing used for baseline and effect of temperature. The specimens were tested at room temperature, 49°C (120°F), and 82°C (180°F). This testing provides a comparison of specimen strength values with all other testing and an indication of temperature effects on strength and modulus.

Table 2. Test Plan for Baseline Material Characterization and Effect of Test Temperature

MATERIAL	SPECIMEN CONFIGURATION AND PLY ORIENTATION				TEST TEMPERATURE AND REPLICATION			PROPERTIES			SUBTOTAL SPECIMENS
	SHORT BEAM SHEAR	FLEXURE	TENSION	COMPRESSION	ROOM	49°C (120°F)	82°C (180°F)	ULT	σ/ϵ	μ	
5208	$[0]_{20}$				5	5	5	—	—*		15
		$[0_2/\pm45/90_2]_s$			5	5	5	—			15
			$[0]_8$		5	5	5	—	—	—	15
			$[\pm45]_{2s}$		5	5	5	—	—	—	15
			$[90]_{20}$		5	5	5	—	—	—	15
			$[\pm45/0/90]_s$		5	5	5	—	—	—	15
				$[0]_{20}$	5	5	5	—	—	—	15
				$[\pm45/0/90]_{3s}$	5	5	5	—	—	—	15
				$[90]_{20}$	5	5	5	—	—	—	15
5209	Repeat 5208 matrix										135
934	Repeat 5208 matrix										135
										Total	405

* Head travel load deflection.

Note:

49/F161-188 material system treated the same as 5208.

AS-1/3501-6 material system treated the same as 5209.

Before testing, all specimens were stored in a drum containing desiccant that provided a dry environment at room temperature. It was determined during The Effect of Moisture program described in sections 8.3 and 10.3 that the actual relative humidity in the storage drum was between 25 and 30%.

8.2 EFFECT OF TIME ALONE

A control group of specimens was carefully stored to evaluate the effects of time on the material systems. Long-term postcure effects will also be evaluated on these specimens. Postcure effects have been observed in both structural adhesives and resin matrix materials exposed to mildly elevated temperatures for relatively short periods of time. It is not known if the contract materials will show this effect when exposed to room temperature for longer periods of time. Time-alone specimens are limited to short beam shear and flexure configurations.

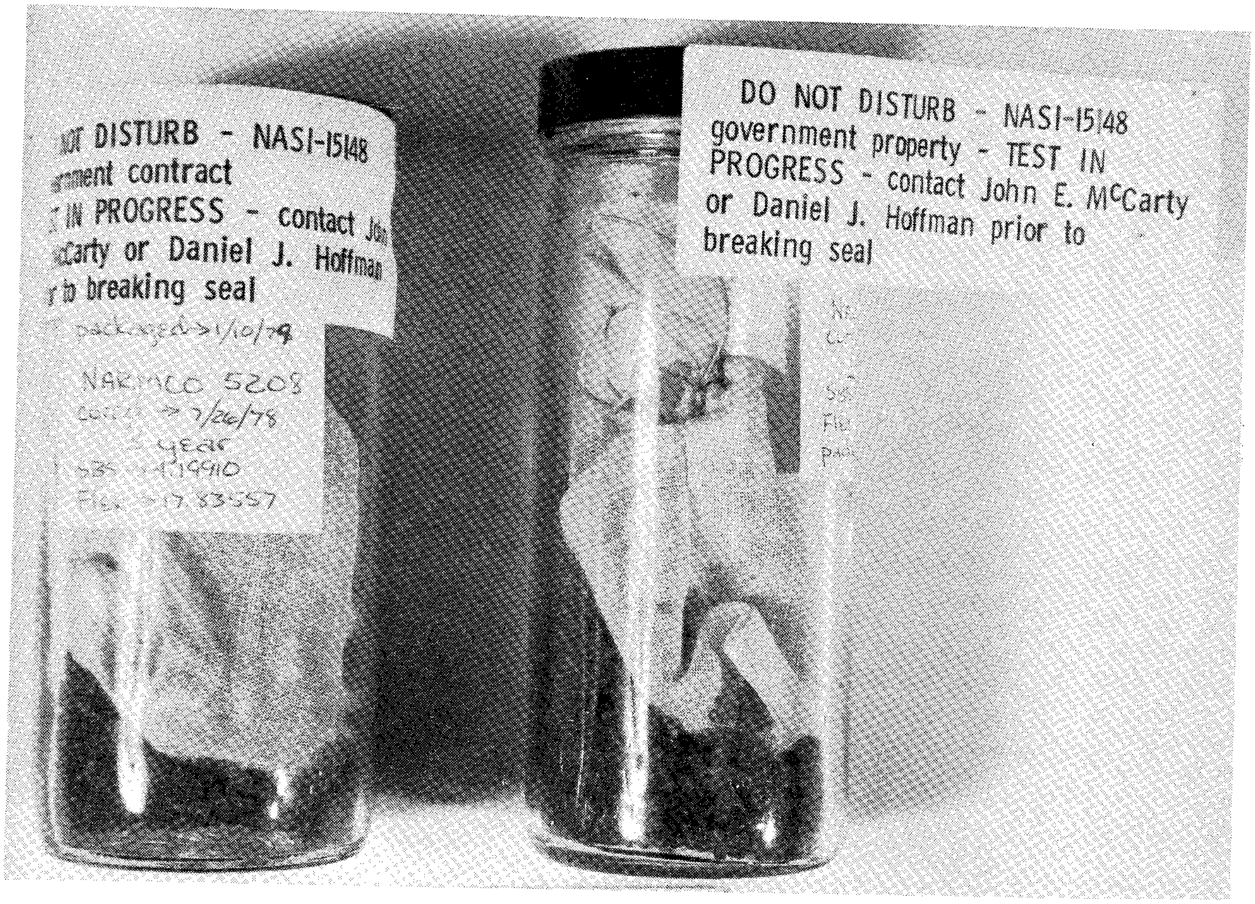


Figure 28. Time Alone Exposure Containers

Prior to deployment, the specimens were stored in a desiccated 55-gal drum. For time-alone exposure, the specimens were sealed in small desiccated jars shown in Figure 28 and stored at room temperature. The desiccant changes color when a certain level of moisture has been absorbed and therefore, can be changed as needed. Because the jars have a higher desiccant-to-volume ratio than the storage drum, they are considered to be a drier environment. It is expected that weight measurements made before and after exposure will reveal a weight loss due to moisture desorption. Exposure durations extend 1, 3, and 10 years. Overall specimen weight change is measured immediately before testing. Half the specimens are tested for residual strength at room temperature and the other half at 82°C (180°F). Table 3 gives a breakdown of the specimens.

8.3 EFFECT OF MOISTURE AND EFFECT OF TIME AND STRESS ON WET SPECIMENS

The Task III laboratory exposure programs contain two test plans specifically oriented toward the effects of moisture. The initial plan, The Effect of Moisture, examines the short-term reversible effect of moisture absorption on graphite-epoxy laminates. Test specimens are exposed to 49°C (120°F) and four different relative humidity conditions: 40, 60, 75, and 95%. Tables 4 and 5 give complete breakdowns of the specimens and exposure conditions. The specimens are exposed until an equilibrium moisture level is achieved. They then are tested statically at both room temperature and the 82°C (180°F) elevated temperature. Instrumentation used on this program is similar to that used on the baseline program. This program will show how various laminates react in the presence of absorbed moisture. It is expected that some plasticization will occur and this will result in strength and stiffness alterations.

Table 3. Test Plan for Effect of Time Alone

MATERIAL	EXPOSURE DURATION AT 21°C (70°F), ≤10% RELATIVE HUMIDITY, yr			SPECIMEN CONFIGURATION AND PLY ORIENTATION		RESIDUAL TEST TEMPERATURE AND REPLICATION		PROPERTIES		SUBTOTAL SPECIMENS
	1	3	10	SHORT BEAM SHEAR	FLEXURE	ROOM	82°C (180°F)	ULT	σ/ϵ	
5208	–	–	–	$[0]_{20}$		5	5	–	–*	30
5208	–	–	–		$[0_2/\pm45/90_2]_s$	5	5	–	–*	30
5209	–	–	–	$[0]_{20}$		5	5	–	–*	30
5209	–	–	–		$[0_2/\pm45/90_2]_s$	5	5	–	–*	30
934	–	–	–	$[0]_{20}$		5	5	–	–*	30
934	–	–	–		$[0_2/\pm45/90_2]_s$	5	5	–	–*	30
									Total	180

*Head travel load deflection.

Note:
49/F161-188 material system treated the same as 5208.
AS-1/3501-6 material system treated the same as 5209.

Table 4. Test Plan for Effect of Moisture

MATERIAL	EXPOSURE ENVIRONMENT AT 49°C (120°F), RELATIVE HUMIDITY, % [3]				SPECIMEN CONFIGURATION AND PLY ORIENTATION				RESIDUAL TEST TEMPERATURE AND REPLICATION		PROPERTIES			SUBTOTAL SPECIMENS
	40	60	75	95	SHORT BEAM SHEAR	FLEXURE	TENSION	COMPRESSION	ROOM	82°C (180°F) [4]	ULT	σ/ϵ	μ	
5208	–	–	–	–	$[0]_{20}$	$[0_2/\pm45/90_2]_s$			5	5	–	– [1]		40
	–	–	–	–					5	5	–			40
	–	–	–	–			$[0]_8$		5	5	–	–	–	40
	–	–	–	–			$[\pm45]_{2s}$		5	5	–	–	–	40
	–	–	–	–			$[90]_{20}$		5	5	–	–	–	40
	–	–	–	–				$[0]_{20}$	5	5	–	–	–	40
	–	–	–	–				$[\pm45/0/90]_s$	5	5	–	–	–	40
	–	–	–	–				$[90]_{20}$	5	5	–	–	–	40
	–	–	–	–	$[0]_{20}$					3 [2]	–	– [1]		12
5209	–	–	–	–	$[0]_{20}$				5	5	–	– [1]		40
	–	–	–	–		$[0_2/\pm45/90_2]_s$			5	5	–			40
	–	–	–	–				$[0]_{20}$	5	5	–	–	–	40
	–	–	–	–	$[0]_{20}$					3 [2]	–	– [1]		12
														132
934	Repeat 5209 matrix													
													Total	596

Note:
[1] Head travel load deflection.
[2] Specimens are dried prior to residual temperature test.
[3] Specimens remain until equilibrium moisture content is achieved.
[4] Control weight specimen will be used in test chamber to identify dryout during stabilization at elevated temperature.
49/F161-188 material system treated the same as 5208.
AS-1/3501-6 material system treated the same as 5209.

Table 5. Test Plan for Effect of Time and Stress on Wet Specimens

MATERIAL	EXPOSURE ENVIRONMENT AT 49°C (120°F), RELATIVE HUMIDITY, %		EXPOSURE DURATION		SPECIMEN CONFIGURATION AND PLY ORIENTATION				RESIDUAL TEST TEMPERATURE AND REPLICATION		PROPERTIES		SUBTOTAL SPECIMENS
	60	95	9 mo	2 yr	SHORT BEAM SHEAR	FLEXURE	TENSION	STRESSED TENSION	ROOM	82°C (180°F)	ULT	CREEP	
5208	–	–	–	–	$[0]_{20}$				5	5	–		40
	–	–	–	–		$[0_2/\pm45/90_2]_s$			5	5	–		40
	–	–	–	–			$[\pm45]_{2s}$		5	5	–		40
	–	–	–	–				$[\pm45]_{2s}$	5	5	–	–	40
	–	–		–	$[0]_{20}$					3*	–		6
5209	–	–	–	–	$[0]_{20}$				5	5	–		40
	–	–	–	–		$[0_2/\pm45/90_2]_s$			5	5	–		40
	–	–		–	$[0]_{20}$					3*	–		6
934	Repeat 5209 matrix												86
												Total	338

*Specimens are dried prior to residual test.

Note:

49/F161-188 material system treated the same as 5208.

AS-1/3501-6 material system treated the same as 5209.

The second test plan is The Effect of Time and Stress on Wet Specimens. Specimens that have been conditioned to 49°C (120°F)/60% relative humidity and 49°C (120°F)/95% relative humidity will be held at temperature for up to two years prior to residual test. A complete description of the specimen configurations is given in Table 5. Unlike the initial moisture program, this study will determine whether or not moisture in a graphite-epoxy laminate can, given sufficient time, cause irreversible degradation. Short beam shear, flexure, tension, and stressed tension specimens are tested.

Test specimens for both programs are preconditioned in desiccators containing a glycerin/water solution. Preparation of the solution is done in accordance with ASTM specification E104-52, method A. Its ability to provide a selected relative humidity has been verified in the Boeing Scientific Research Center. Initially, two instruments were used for verification: a Panametrics model 2000 hydrometer that converts a dew point measurement to relative humidity and a Honeywell model 611 that measures the percentage of relative humidity (RH) directly.

The humidity chambers consisted of two Pyrex desiccators with glycerin/water solutions formulated to achieve 59% RH and 74% RH at room temperature. These solutions convert to nominal 60 and 75% values when elevated to the 49°C (120°F) exposure temperature. The Panametrics instrument is highly accurate at low relative humidities but is less reliable at the high humidities involved with these desiccators. Results from the Honeywell instrument are used to verify the glycerin/water solutions. The desired humidities can be achieved with an accuracy of ±2%. A final check is made in the 49°C (120°F) environment using a Rustrak strip chart recorder. Figure 29 shows one of the desiccators undergoing checkout with the strip chart recorder.

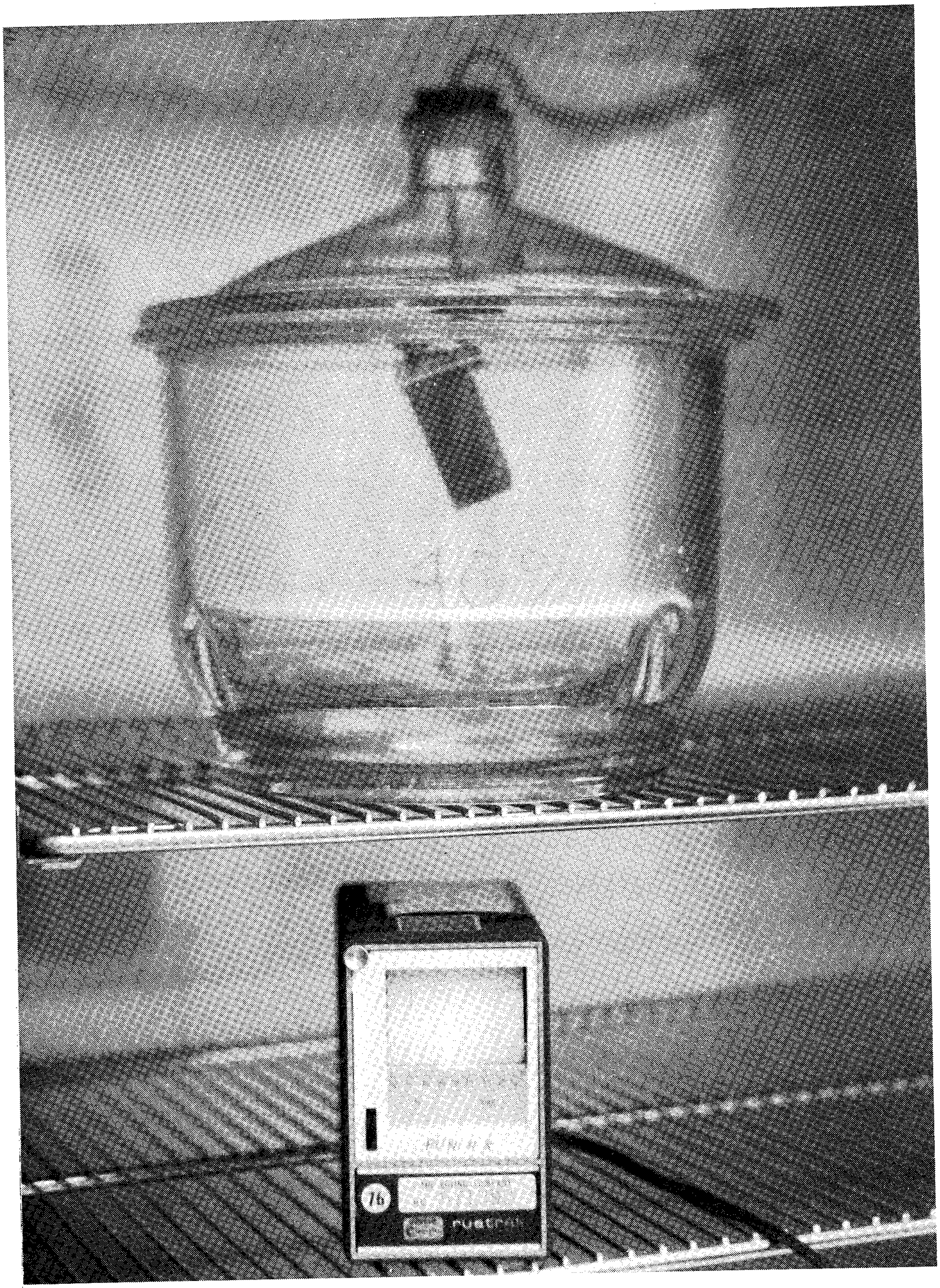


Figure 29. Rustrak Checkout of Humidity Environment

8.4 WEATHEROMETER

The weatherometer is an environmental exposure chamber consisting of continuous UV radiation and an intermittent water spray. Figure 30 shows the inside of the exposure chamber with the specimens held vertically around the perimeter. It is an effective simulation of the degrading effects of sunlight coupled with the erosive effects of surface water such as rain. In addition, there is the effect of the water washing away the UV-degraded byproducts of the surface resin, thereby providing a fresh resin surface and continuing the degrading/eroding process. Only flexure specimens and paint evaluation specimens are involved. Table 6 gives a breakdown of specimens and test specifications.

Table 6. Test Plan to Evaluate Effect of Weatherometer Cycles

MATERIAL	EXPOSURE DURATION, mo			PAINTED	UNPAINTED	TEST SPECIMEN AND PLY ORIENTATION	RESIDUAL TEST TEMPERATURE AND REPLICATION		PROPERTIES	SUBTOTAL SPECIMENS
	6	12	24			FLEXURE	ROOM	82°C (180°F)	ULT	
5208	–	–	–	–	–	$[0_2/\pm45/90_2]_s$	5	5	–	60
			–	–	–	$[0_2/\pm45/90_2]_s$		3*	–	6
5209	–	–	–	–	–	$[0_2/\pm45/90_2]_s$		5	–	30
			–	–	–	$[0_2/\pm45/90_2]_s$		3*	–	6
934	Repeat 5209 matrix									36
									Total	138

*Specimen is dried prior to residual temperature test.

Note:
49/F161-188 material system treated the same as 5208.
AS-1/3501-6 material system treated the same as 5209.

Half of the flexure specimens remain unpainted, and the other half are painted with the standard finish used on this contract and described in section 6.3. The paint evaluation specimens are 6.35 x 11.43 cm (2.5 x 4.5 in) coupons made of 0.51 mm (0.020 in) titanium that also is painted with the standard finish. The painted specimens are intended to determine the protective effectiveness of paint. The paint is not considered a barrier to moisture, but it may be effective protection against UV degradation. Stainless steel fixtures, Figure 31, were designed to hold 20 flexure specimens and one paint evaluation specimen each. The fixtures provide for two-sided moisture access, but only one surface is exposed to UV radiation. Each 2-hour exposure cycle specifically consists of continuous carbon-arc lamp irradiation with an 18-min water spray.

Specimens of T300/5208 are divided between testing at room temperature and at 82°C (180°F). Specimens of T300/5209, and T300/934 are all tested at 82°C (180°F) only. Weight change, residual strength, and glass transition temperature data are being collected.

8.5 WEBBER CHAMBER–GROUND-AIR-GROUND

The Webber chamber is an environmental exposure device for simulating the conditions of a standard commercial aircraft flight cycle operating from a hot, moist, tropical climate. Figure 32 shows the Webber chamber with specimens in the exposure compartment. Specifically, cycles are 1-hour long and consist of 4 phases as presented in Figure 33. The

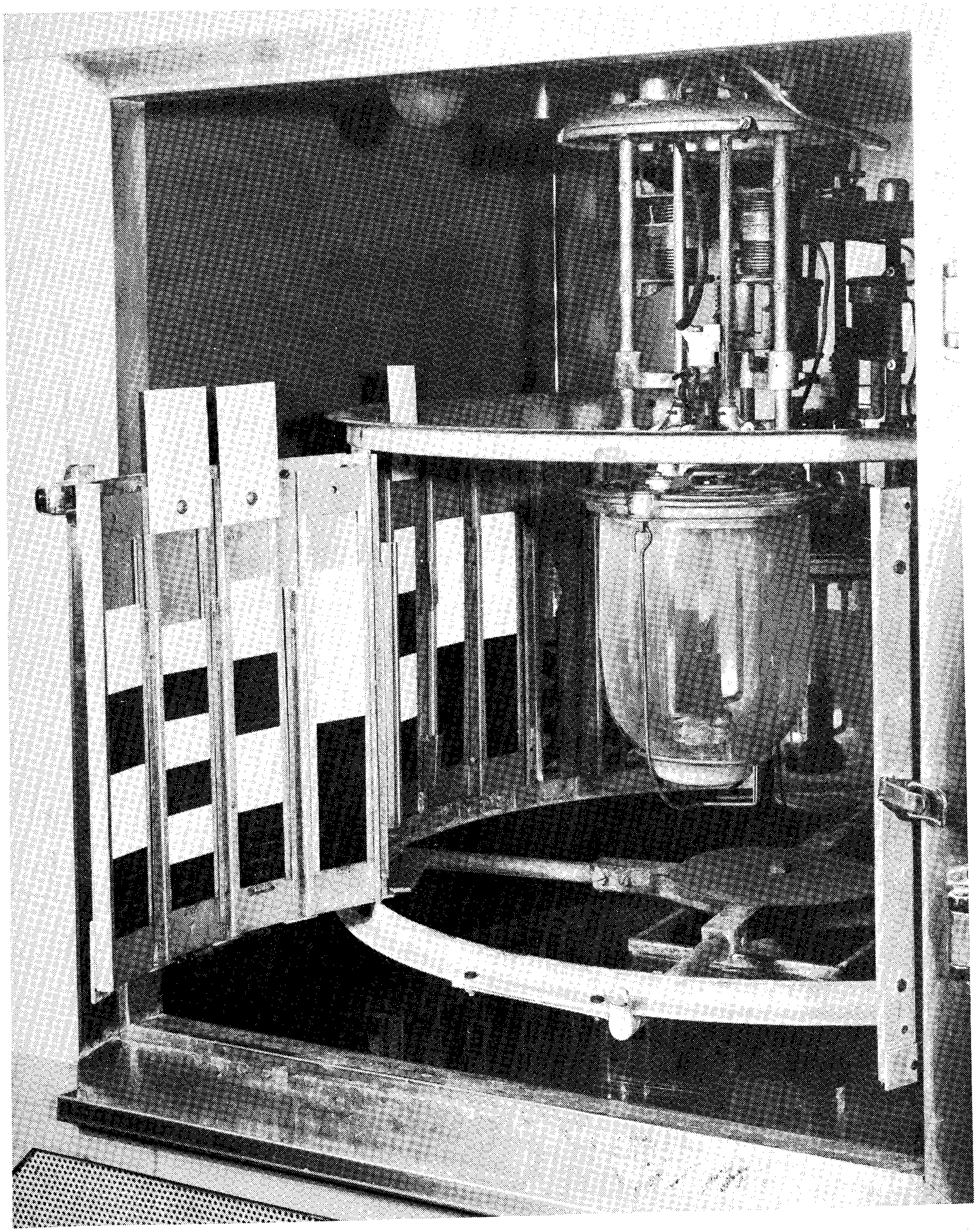


Figure 30. Interior of Weatherometer Exposure Chamber

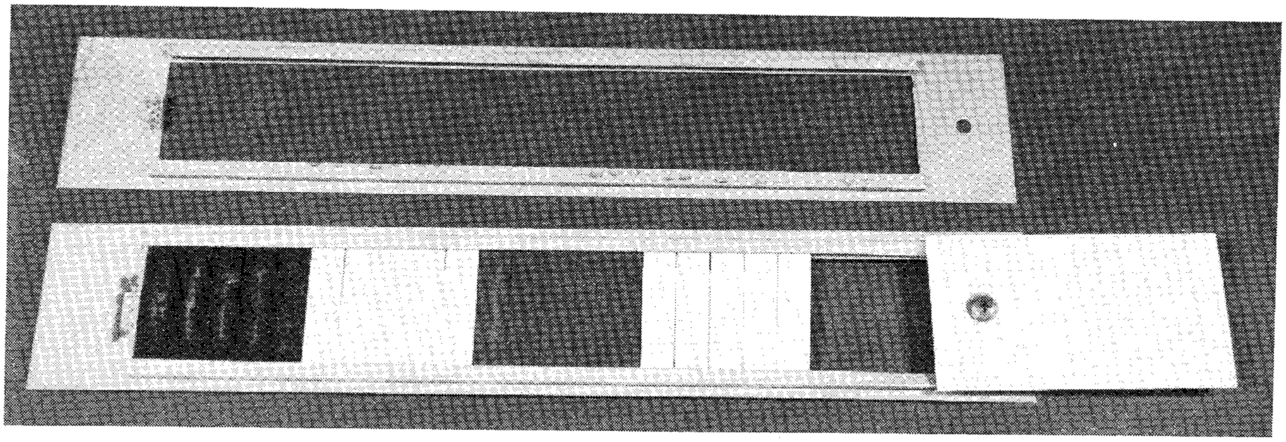


Figure 31. Weatherometer Specimen Holders

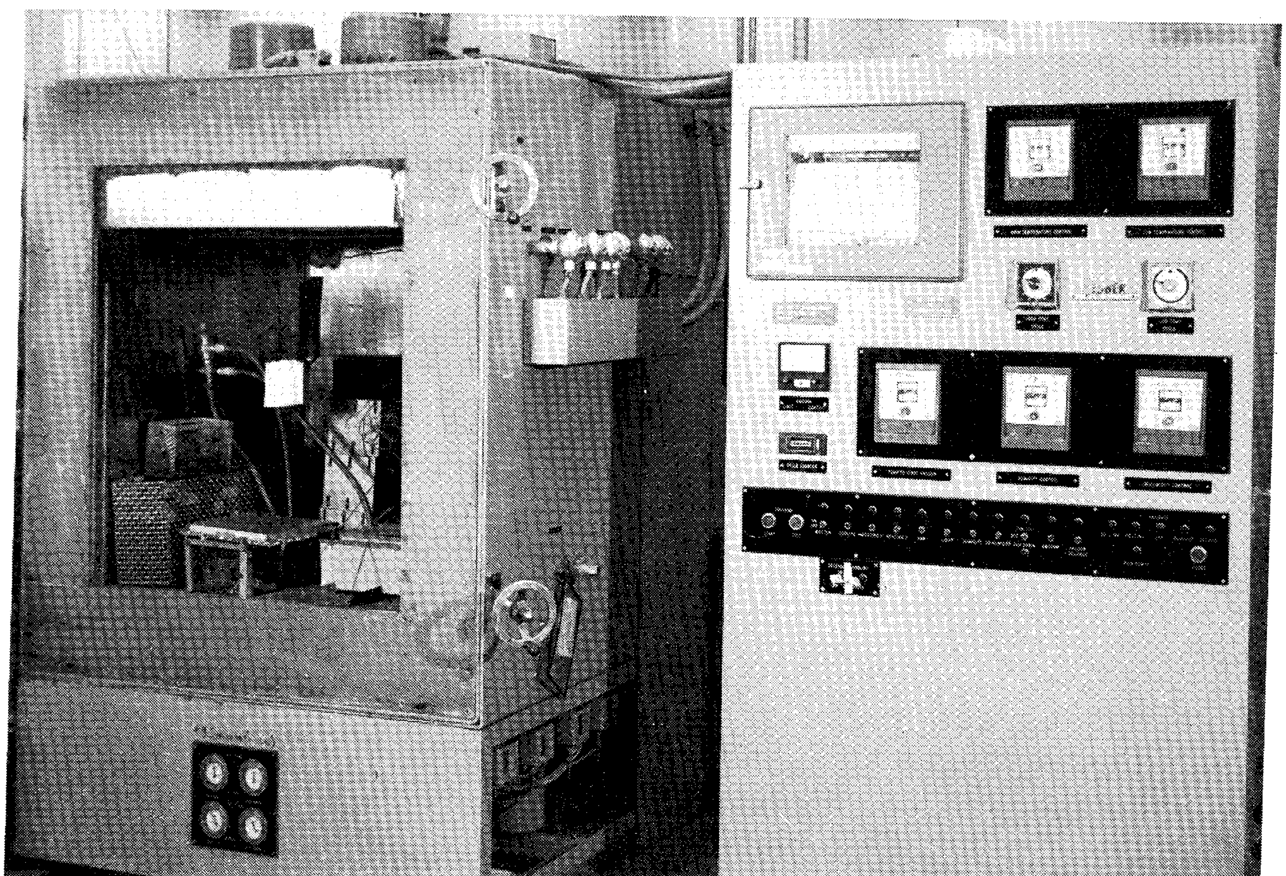


Figure 32. Webber Chamber for Ground-Air-Ground Exposure

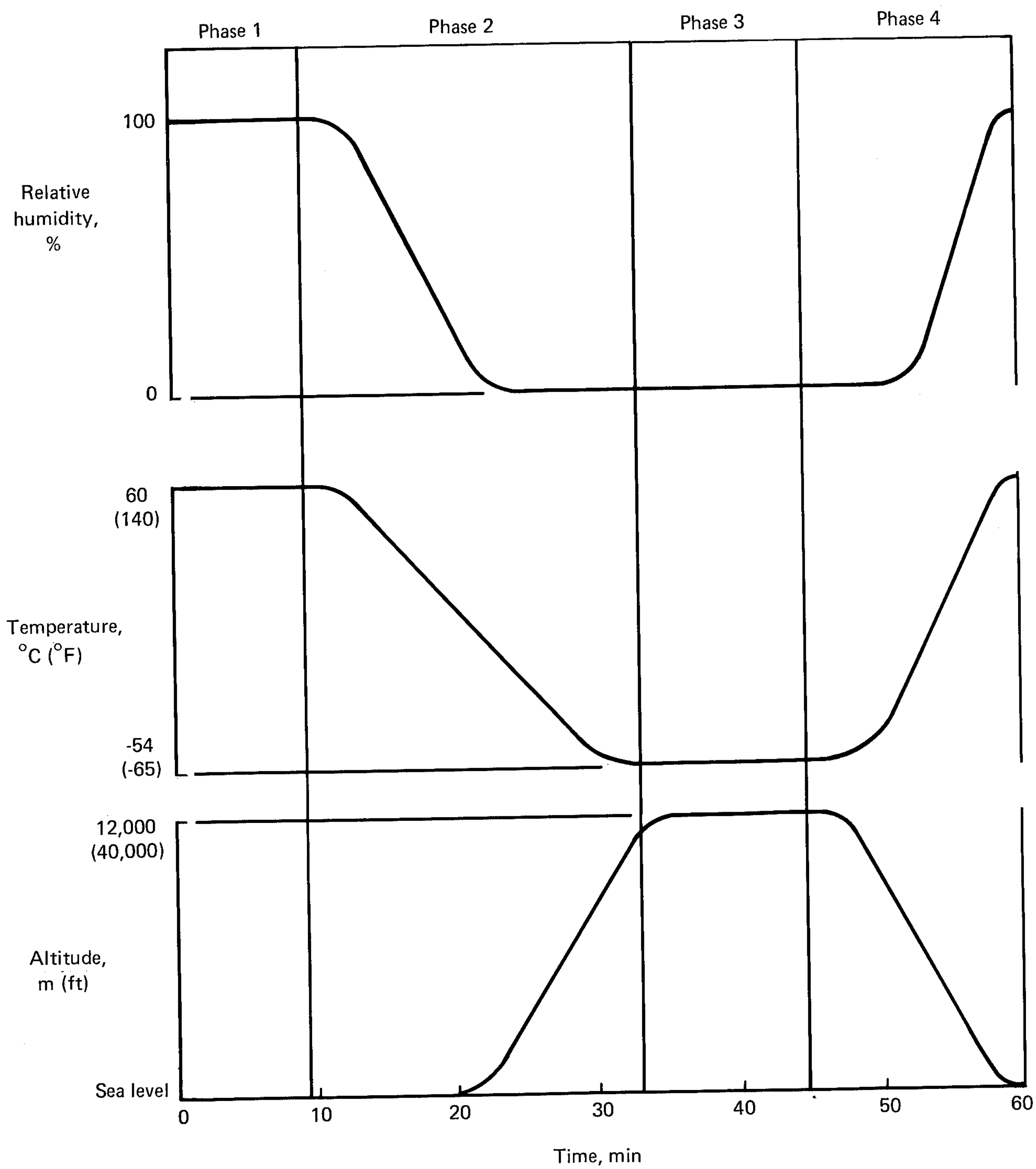


Figure 33. Webber Chamber and Ground-Air-Ground Cycle Detail

first phase is 10 minutes long with constant conditions of 49°C (120°F), condensing relative humidity, and standard atmospheric pressure simulating a hot runway condition. The second phase is a 25-minute steady transition from the first phase to the third phase and simulates aircraft takeoff and climb to cruise altitude. The third phase is a 10-minute simulation of aircraft at cruise altitude with conditions of -54°C (-65°F) 0% relative humidity, and 12,000m (40,000 ft) altitude pressure. The fourth phase is a 15-minute transition from phase 3 back to the conditions of phase 1 completing the cycle.

Test specimens involved include short beam shear, flexure, ±45-deg tension, and pre-stressed ±45-deg tension. Painted titanium coupons are included to assess the paint film's ability to withstand freeze-thaw cycles. Microcrack analysis is performed on selected specimens after exposure durations of 1, 2, and 3 months. Residual strength measurements are made after exposure durations of 6, 12, and 24 months. Weight change measurements were performed on selected specimens at finer exposure intervals. Table 7 gives a complete description of the specimens involved and the exposures.

Table 7. Test Plan for the Effect of Simulated Ground-Air-Ground Cycles

MATERIAL	ENVIRONMENTAL CYCLE AND EXPOSURE DURATION						SPECIMEN CONFIGURATION AND PLY ORIENTATION				RESIDUAL TEST AND TEMPERATURE REPLICATION		PROPERTIES		SUBTOTAL SPECIMENS
	QUANTITATIVE, mo			QUALITATIVE, mo			SHORT BEAM SHEAR	FLEXURE	TENSION	STRESSED TENSION	ROOM	82°C (180°F)	ULT	CREEP	
	6	12	24	1	2	3									
5208	–	–	–	–	–	–	$[0]_{20}$				5	5	–		60
	–	–	–	–	–	–		$[0_2/\pm45/90_2]_s$			5	5	–		60
	–	–	–	–	–	–			$[\pm45]_{2s}$		5	5	–		60
	–	–	–	–	–	–				$[\pm45]_{2s}$	5	5	–	–	60
			–			–	$[0]_{20}$					3*	–		6
5209	–	–	–	–	–	–	$[0]_{20}$				5	5	–		60
	–	–	–	–	–	–		$[0_2/\pm45/90_2]_s$			5	5	–		60
			–			–	$[0]_{20}$					3*	–		6
934	Repeat 5209 matrix														126
														Total	498

*Specimens are dried prior to residual temperature test.

Note:

48/F161-188 material system treated the same as 5208.

AS-1/3501-6 material system treated the same as 5209.

9.0 LONG-TERM RESULTS

9.1 EXPOSURE HISTORY AND STATUS

The status of all deployed specimens is shown in Table 8 for flight exposure and Table 9 for ground exposure. The dates represent when specimens were actually removed from exposure or when they were projected for removal. The designated specimen group was removed from the airplane or ground rack on the approximate given date and returned to Seattle for postexposure evaluation.

9.2 STRENGTH TEST RESULTS

Individual specimen test data and results from long-term environmental exposure were reported as they became available in the contract quarterly reports. Results from testing through January, 1981 can be found in References 13 and 14. The results include both residual strength as a percent of baseline strength and specimen weight change during exposure. Positive weight changes are gains, and negative weight changes are losses. All results through July, 1981 have been included in Appendix A.

The results are presented in the following figures. Several of the figures present the range of strength measurements for each of the materials with all the exposure locations—ground and flight, solar, nonsolar, and interior. It should be noted that these results are not from all exposure locations. The 1-year results are from Honolulu, Wellington, and Dryden. The 2-year results are from Honolulu and Dryden only. Other figures are presented showing individual exposure cases for the locations with 2-year data available.

Table 8. End Dates (Actual or Projected) for Flight Specimen Exposure

Nominal exposure, yr	1	2	3	5	7	10
Aloha Airlines	3-14-80*	3-27-81*	3-14-83	3-27-88	3-27-88	2-16-89
Air New Zealand	11-25-80*	10-30-81	11-25-83	11-25-88	9-15-88	7-2-89
Southwest Airlines	6-21-81	2-27-82	6-21-84	6-14-89	2-27-89	6-22-90

*This report contains data for these exposures.

Table 9. End Dates (Actual or Projected) for Ground Rack Exposure

Nominal exposure, yr	1	2	3	5	7	10
NASA-Dryden	2-11-80*	10-14-80*	10-30-81	10-30-83	10-30-85	10-30-88
Honolulu	3-13-80*	2-19-81*	2-9-82	2-9-84	2-9-86	2-9-89
Wellington	11-24-80*	7-4-81	7-4-82	7-4-84	7-4-86	7-4-89
Dallas	6-21-81	4-18-82	4-18-83	4-18-85	4-18-87	4-18-90

*This report contains data for these exposures.

Short Beam Shear—The overall room temperature short beam shear test results are given in Figure 34. Strength reductions in general did not drop below 80% of baseline. The T300/5208 tends to be more resistant to degradation but has wider scatter. One short beam shear strength value for T300/5208 2-year exposure is below 60% of baseline and inflates the range of the values. The value represents an average of three tests that were grouped closely together. There are no readily apparent explanations for this anomaly, but further investigations are being made.

The test results for specimens tested at 82°C (180°F) are shown plotted in Figure 35. Strengths show more decrease than for the room temperature tests. Again, the T300/5208 had the least percentage drop in residual strength of three materials but the widest scatter among locations.

To illustrate possible differences between the exposure locations, individual strength results are plotted in several of the following figures. Each point represents three specimen tests. Only exposure locations for which 2-year data are available have been included—Dryden, Honolulu, and Aloha Airlines. Figure 36 shows these results for room

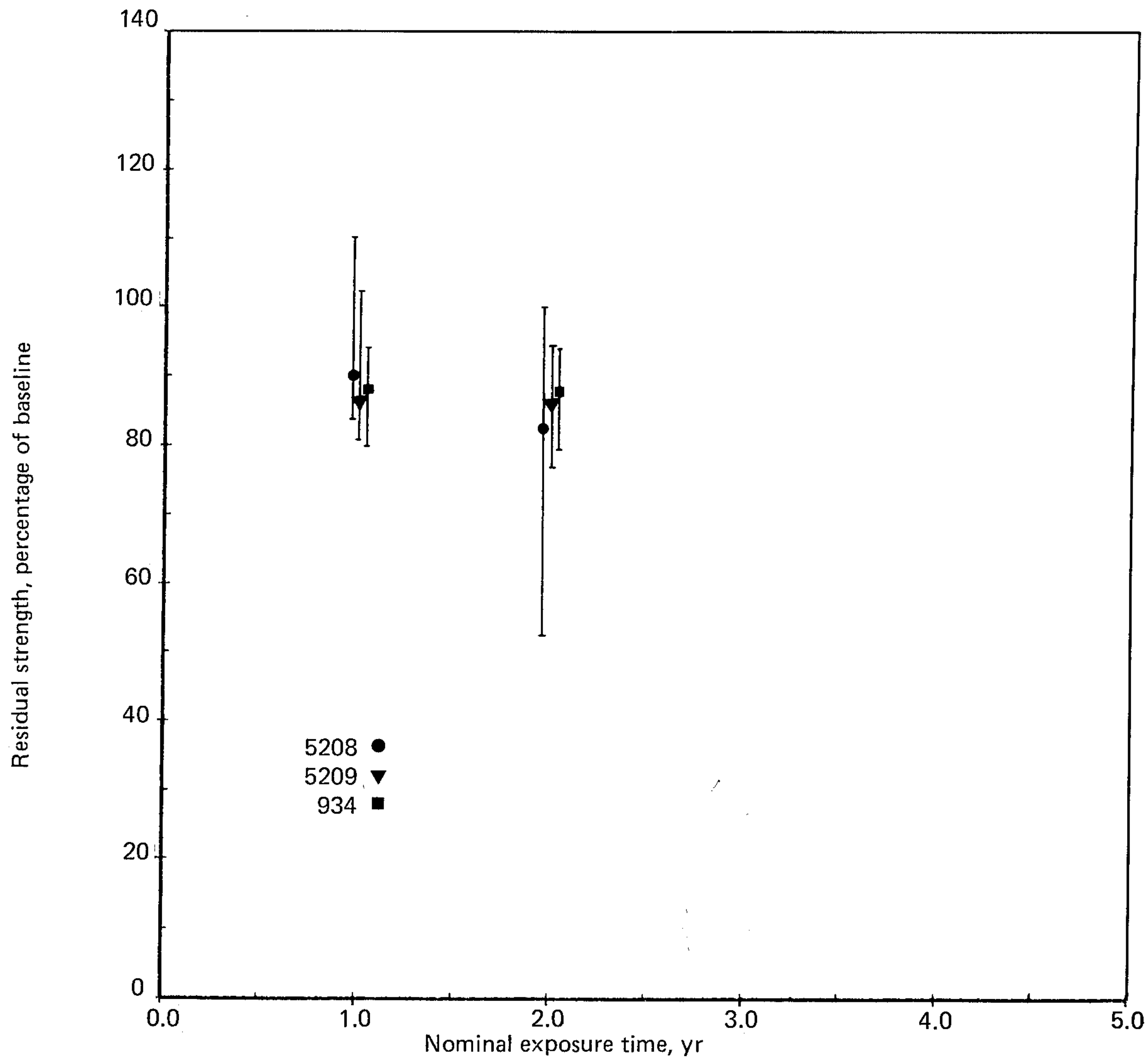


Figure 34. Short Beam Shear—Room Temperature

temperature tested short beam shear. Except for T300/5208, the data are grouped closely. The shear strengths for Dryden specimens are higher than those from Honolulu and Aloha Airlines. This would be expected since Hawaii has a wetter environment than Dryden and, therefore, Hawaii specimens would have a higher moisture content. It is generally believed that moisture content is inversely related to shear strength as demonstrated in section 10.3.

Assuming that dryout weight measurements of rider specimens are good estimates of moisture content in similarly exposed specimens, the specimens from the Hawaii locations do, in fact, contain substantially more moisture than the Dryden specimens (Appendix A, Tables A-6 through A-19).

Figure 37 shows individual results for the short beam shear tests performed at 82°C (180°F). The separation among the different exposure locations is more pronounced than for the room temperature test results.

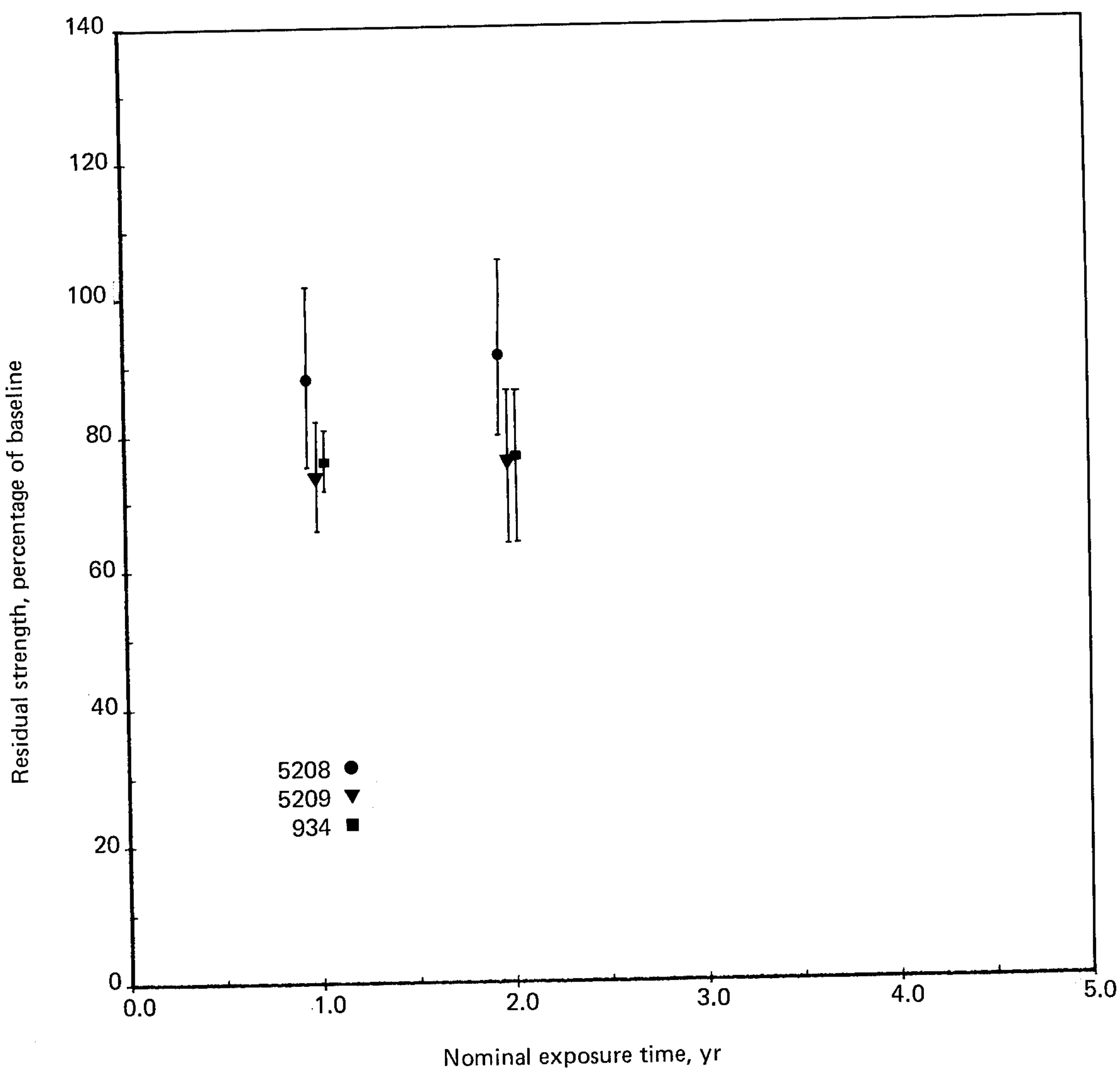


Figure 35. Short Beam Shear—82° C (180° F)

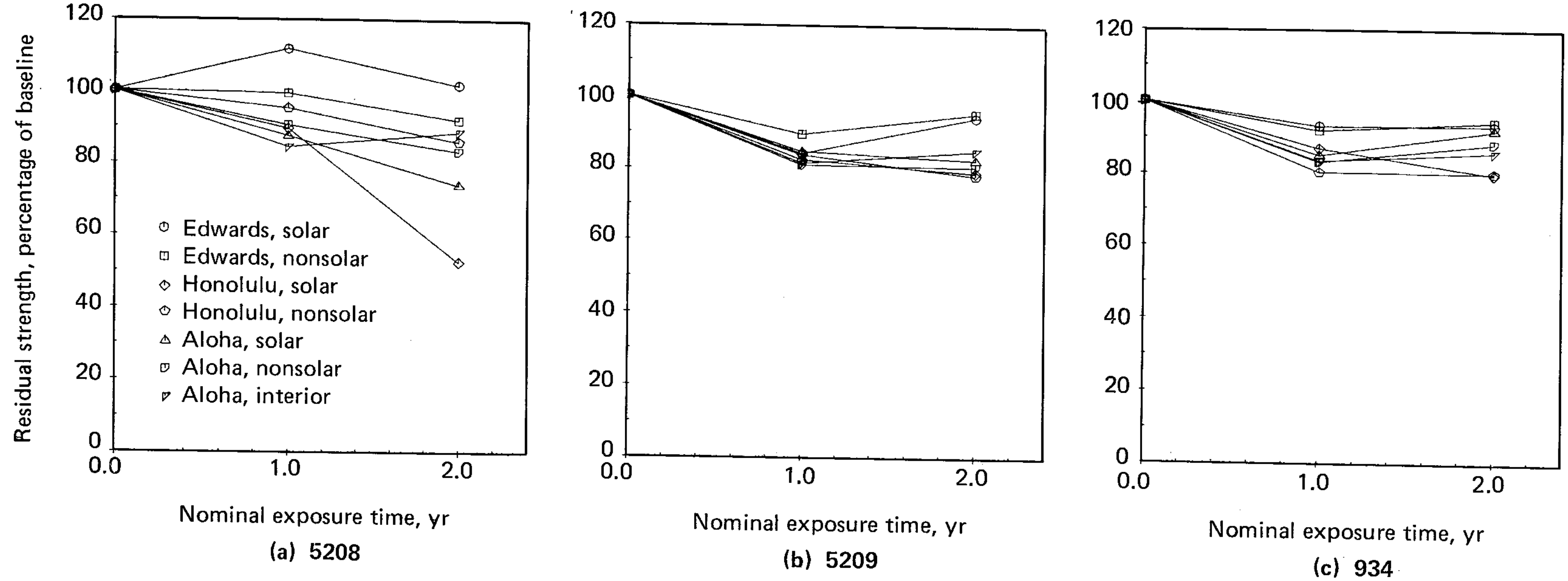


Figure 36. Individual Results, Short Beam Shear—Room Temperature

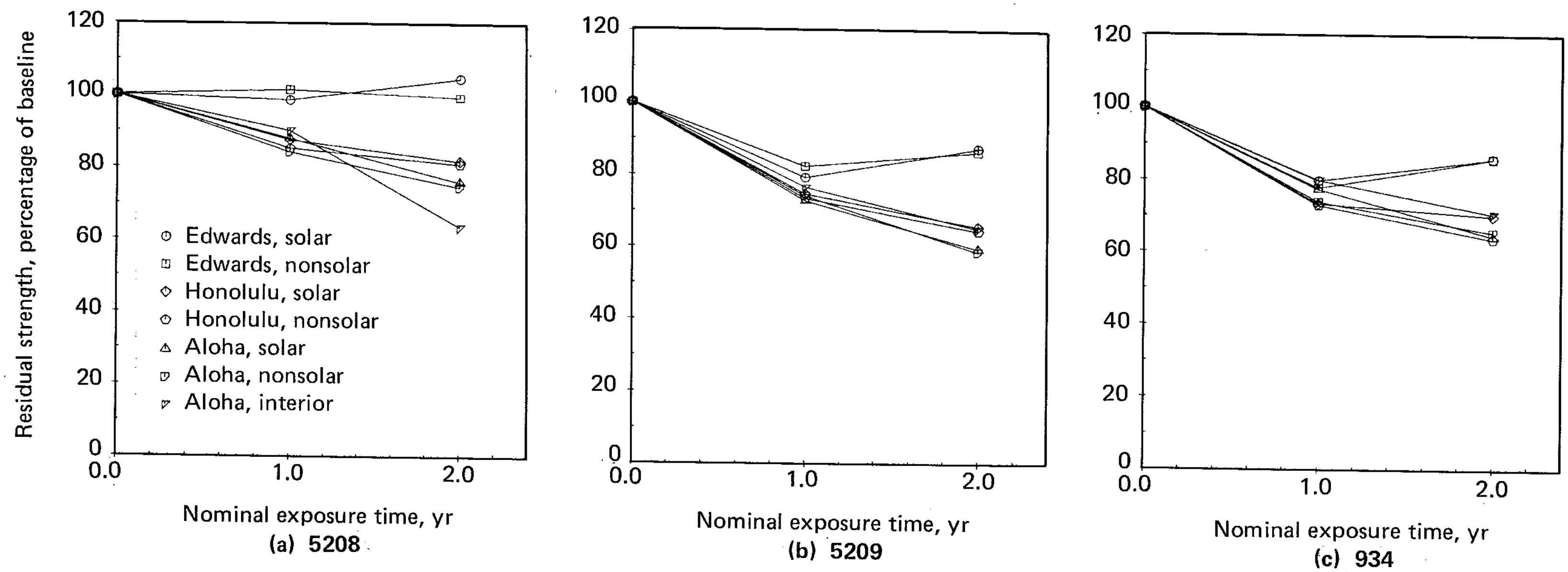


Figure 37. Individual Results, Short Beam Shear—82°C (180°F)

Three exposure conditions, Dryden (ground), Honolulu (ground), and Aloha Airlines (flight), begin to reveal group differences after 2 years of exposure. The Dryden specimens again show the most strength, followed by the Honolulu specimens, with the specimens from Aloha Airlines showing the least strength. No apparent shear strength difference is demonstrated betwen solar and nonsolar exposure. The Aloha flight interior shear strength for T300/5208, however, was 11% below the solar and nonsolar cases. The possible significance of this point will be discussed with the flexure specimen results.

Flexure—The overall room temperature flexure test results are shown in Figure 38. These strengths are grouped around 100% of baseline strength, and they have less scatter than the short beam shear strengths.

The 82°C (180°F) flexure test results are shown in Figure 39 and reveal more scatter than for the room temperature case. The T300/5208 and T300/934 strengths remain grouped around 100% of baseline strength, but some of the T300/5209 strengths dropped to 71%.

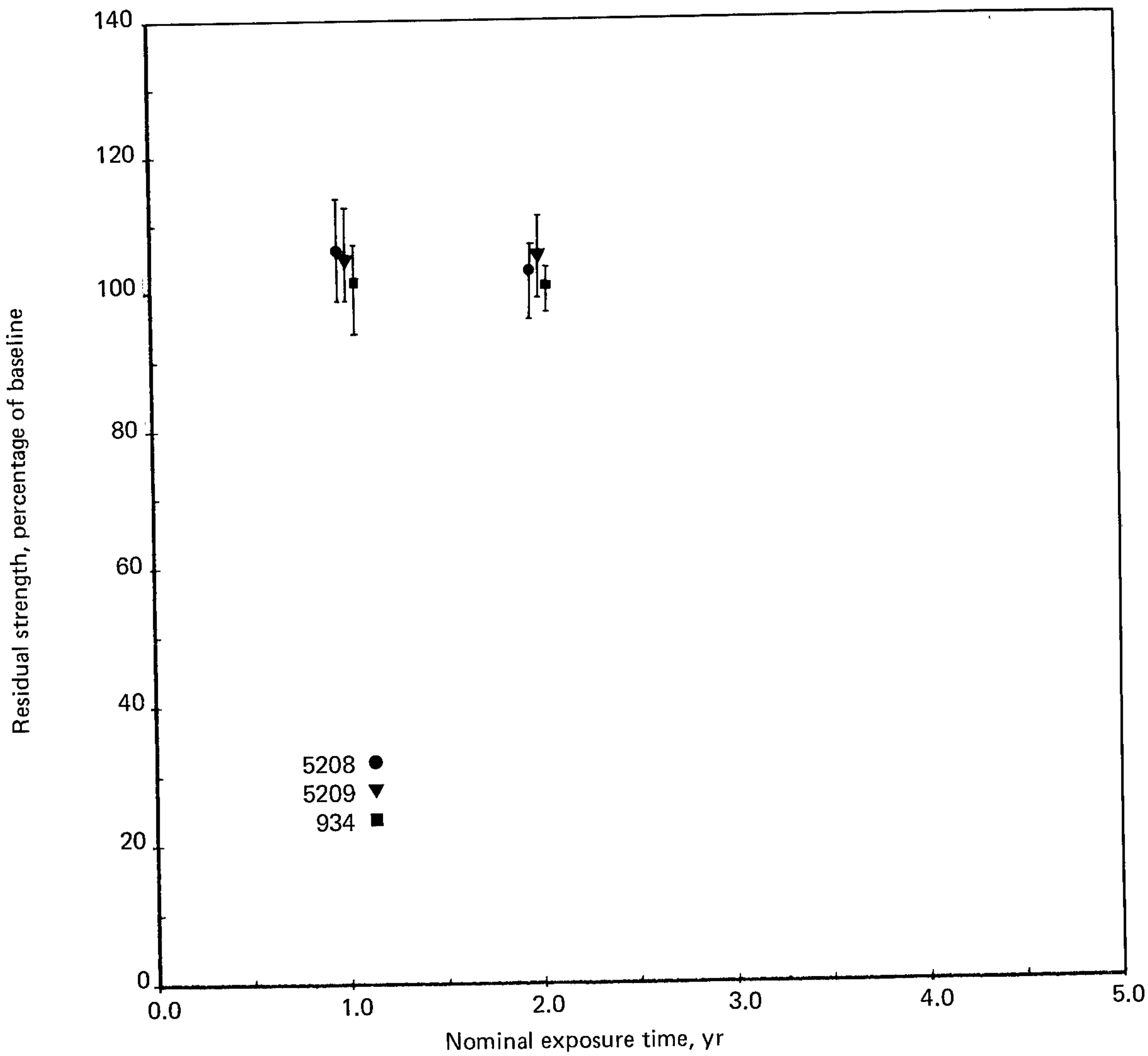


Figure 38. Flexure—Room Temperature

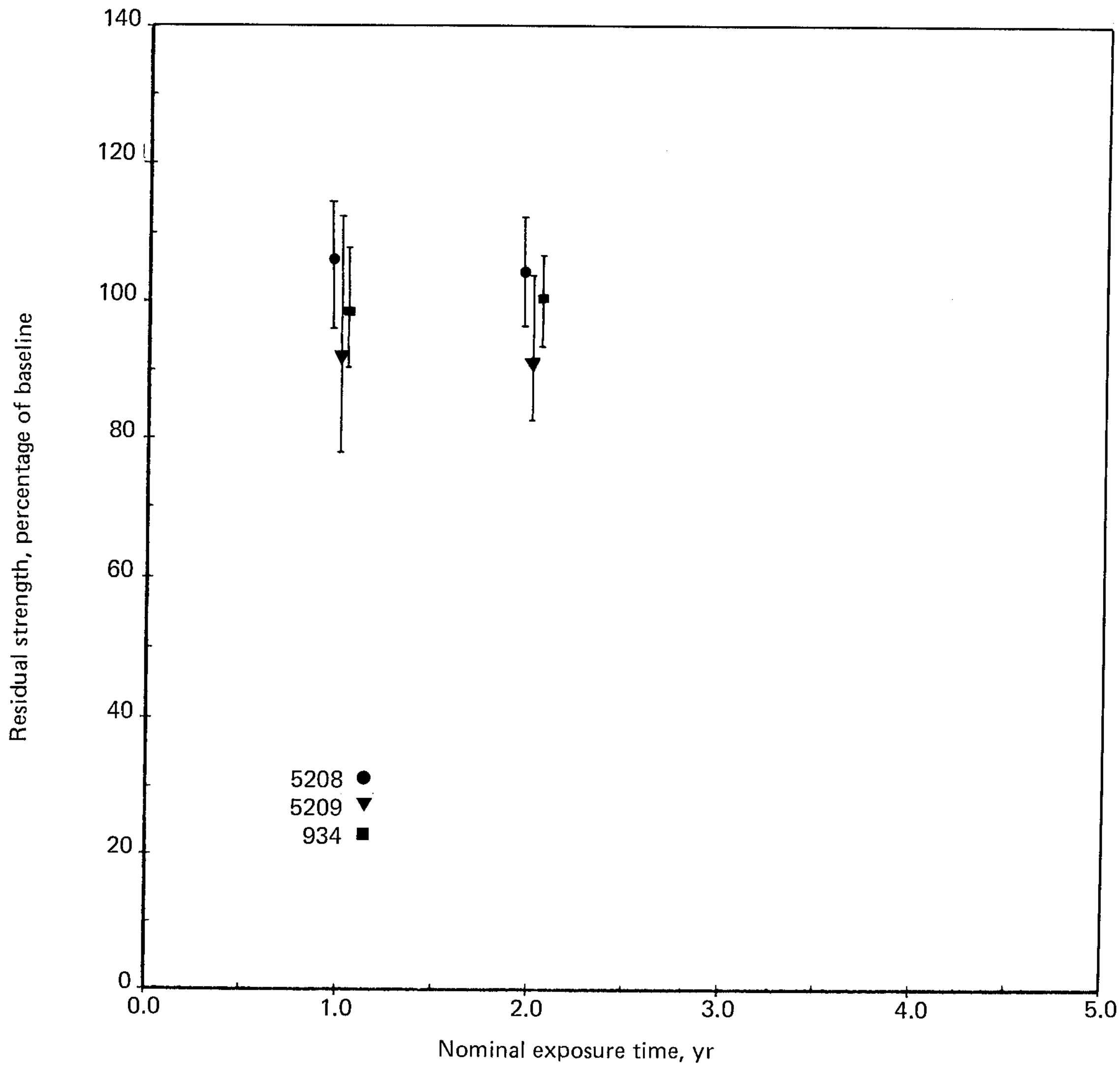


Figure 39. Flexure—82°C (180°F)

Figure 40 shows the individual exposure location results for room temperature flexure tests for 2 years. All the results are closely grouped around 100% of baseline strength. No other trends are readily evident.

Figure 41 shows the individual exposure location results for the flexure tests performed at 82°C (180°F). The elevated temperature tests reveal differences in the locations better than the room temperature tests, and several definite trends are evident. The flexure specimens exposed at Dryden are, like the short beam shear specimens, stronger than the specimens exposed at Honolulu and on Aloha Airlines. There is a trend for the specimens exposed on the ground at Honolulu to be stronger than the specimens exposed on the airplanes. The nonsolar specimens tend to be stronger than the specimens exposed to solar radiation for ground exposure at Honolulu, Aloha Airlines, and Dryden. This is not the case for flight-exposed specimens.

Figure 41 shows an abrupt drop in the strength of the flight interior flexure specimens with 2 years of exposure for all three materials. The flight interior short beam shear strength for T300/5208 also was low after 2-years' exposure. Upon return to Boeing, these

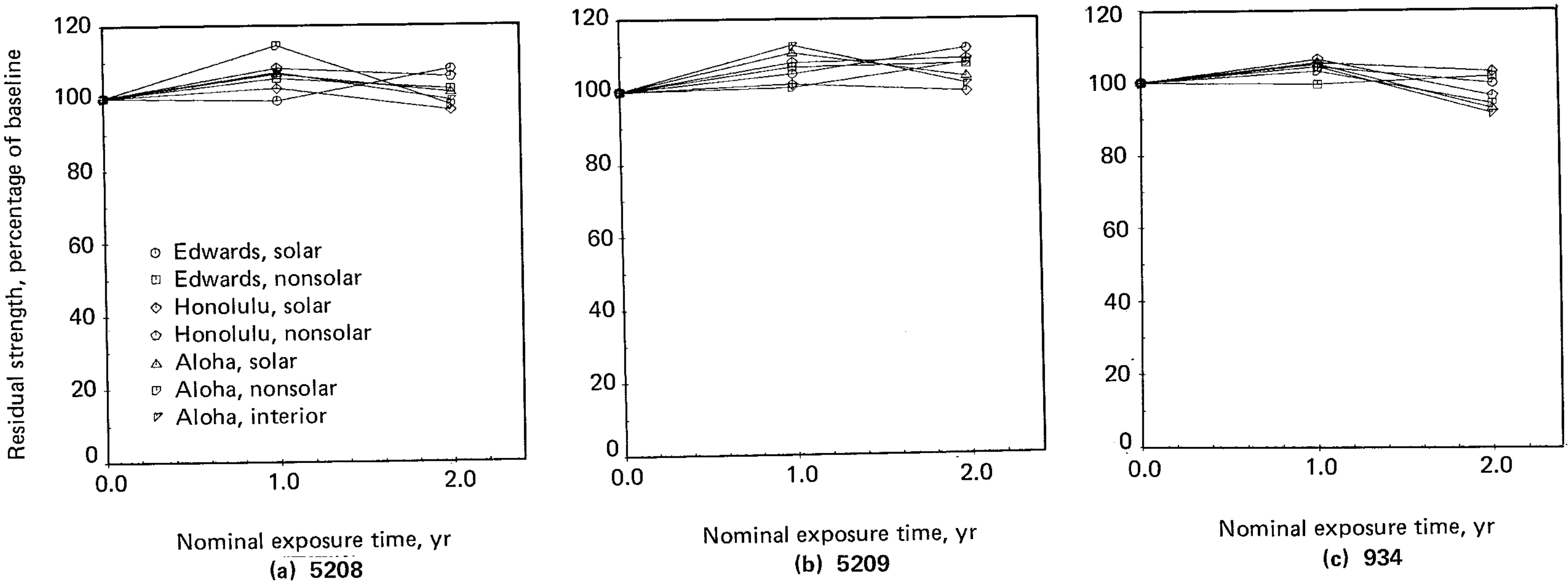


Figure 40. Individual Results, Flexure—Room Temperature

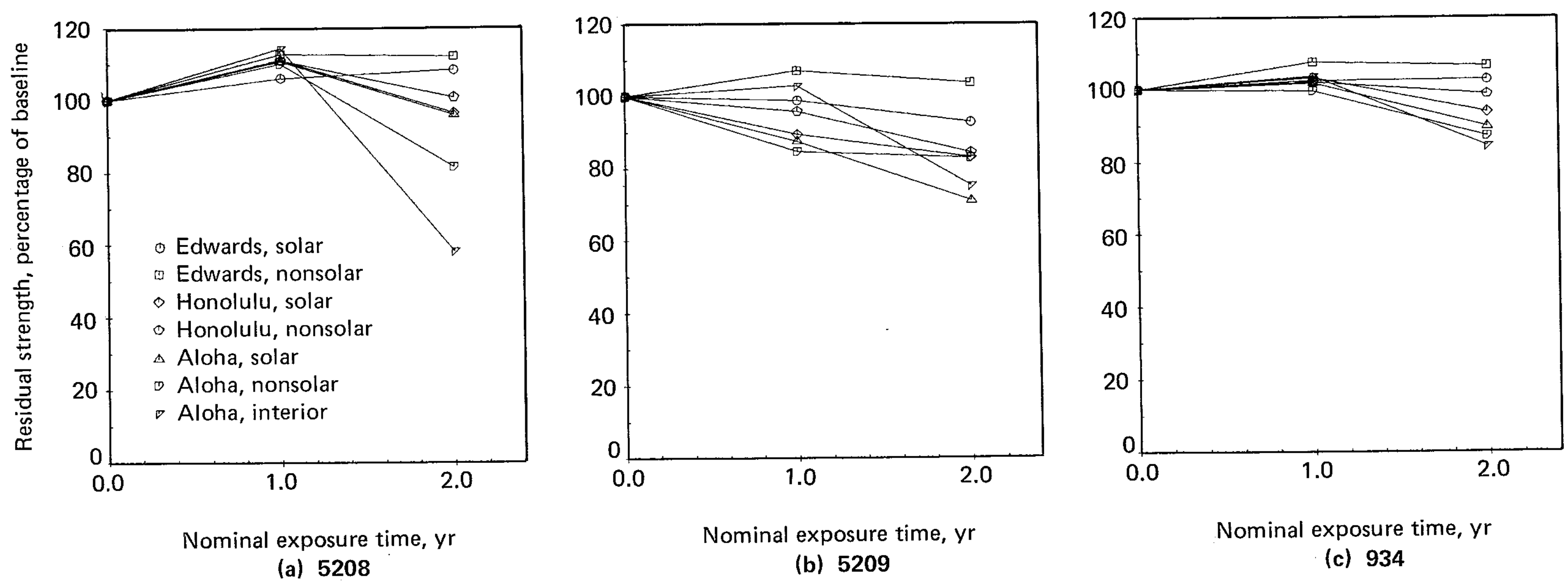


Figure 41. Individual Results, Flexure—82°C (180°F)

2-year specimens appeared to have been sprayed with hydraulic fluid. The sensitivity of the flexure specimen to surface effects is a possible explanation for its apparent sensitivity to solar effects and surface hydraulic fluid. The flexure specimens also may be sensitive to moisture content since the Dryden specimens were consistently stronger than the specimens from Honolulu and Aloha Airlines.

±45-deg Tension—The overall room temperature tension test results are presented in Figure 42. All strengths are above 100% of baseline. Figure 43 shows the overall strength results for specimens tested at 82°C (180°F). As with shear and flexure strengths, the testing done at an elevated temperature produces more strength decrease than testing done at room temperature; most were above 100% of baseline. The T300/5209, however, showed a drop in strength after both 1- and 2-year exposure.

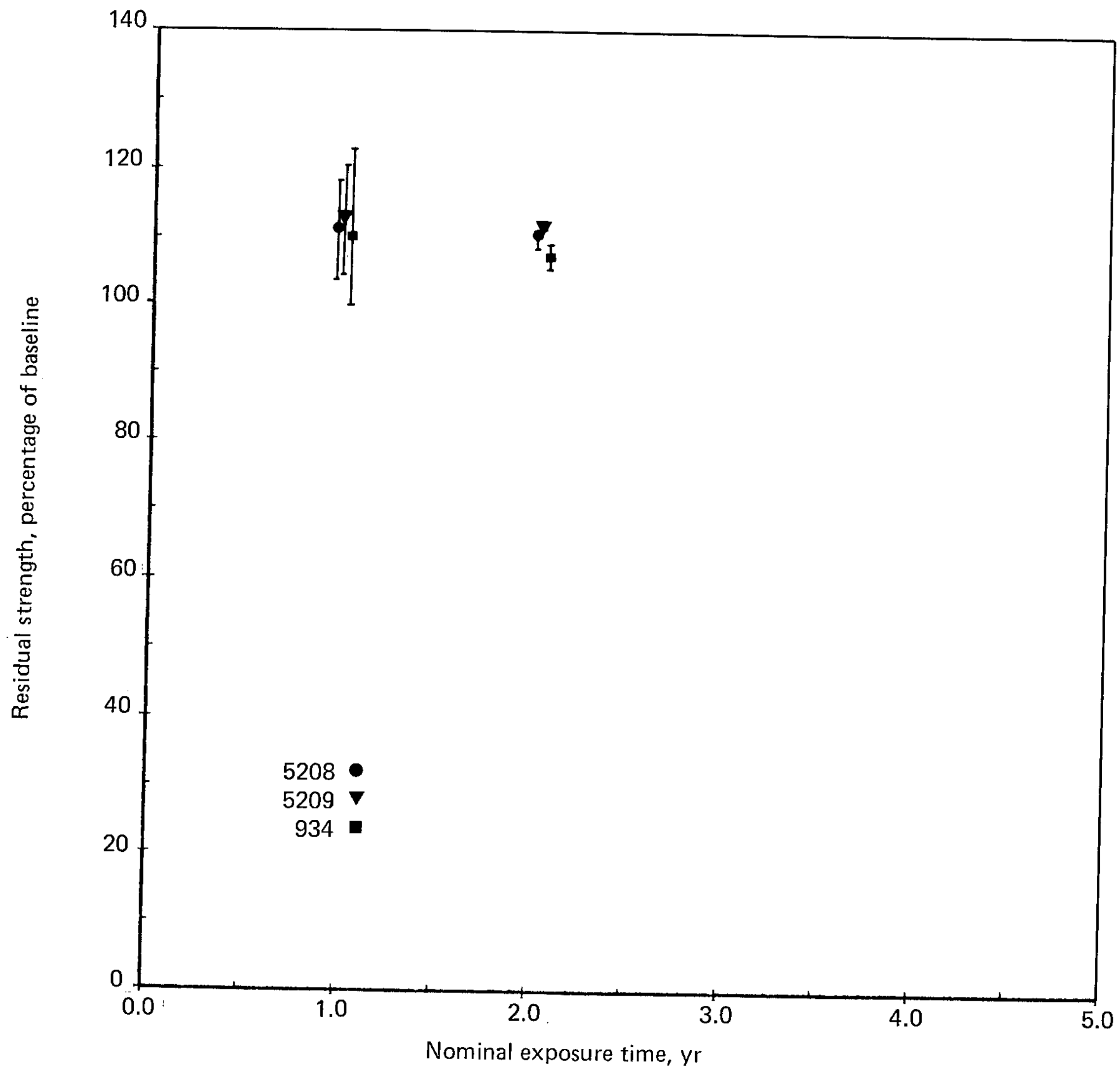


Figure 42. ±45-deg Tension—Room Temperature

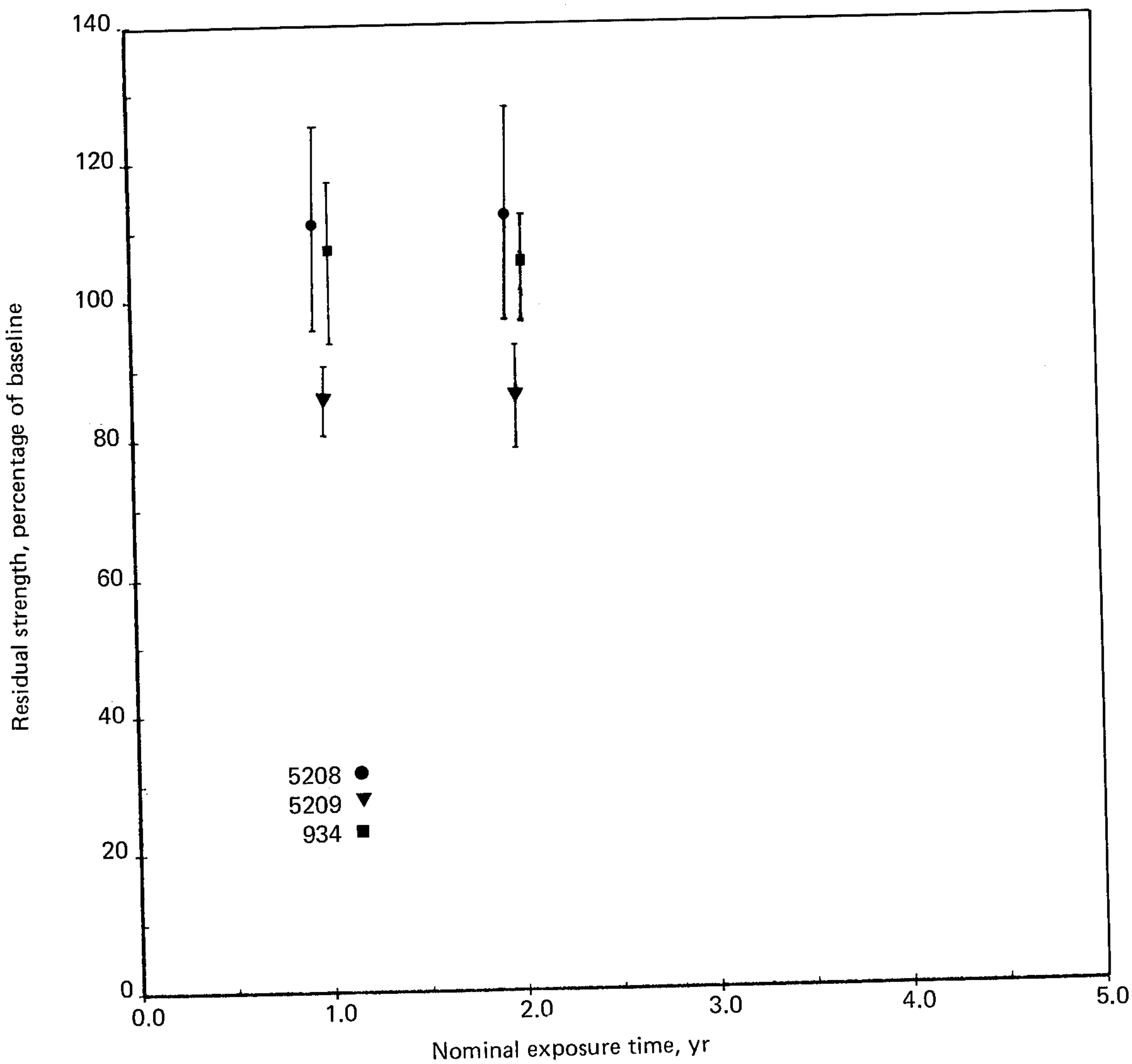


Figure 43. ±45-deg Tension—82°C (180°F)

Short Beam Shear Dryout—The strength degrading effects of moisture on short beam shear strength is demonstrated by comparing the strengths before and after dryout. Figure 44 shows 1- and 2-year strength data of dried-out short beam shear specimens. A comparison of Figure 44 with Figure 37 shows that dried-out specimen shear strengths are generally higher than undried (moist) specimen shear strengths.

Stressed Tension—The ±45-deg tension specimens exposed in a stressed state were tested at 82°C (180°F). When the strength results shown in Figure 45 are compared with the unstressed tension strength results in Figure 43, the same trends are apparent. The strengths of T300/5208 and T300/934 are above 100% of baseline, and the strength of T300/5209 is below 100% of baseline. As yet there are no apparent significant differences between the unstressed and stressed tension cases.

Compression—Problems with the gripping tabs on some compression specimens have limited the amount of useful data for long-term exposure compression strength. Gripping tabs have slipped on some of the specimens tested at high temperature. These specimens will be retabbed, and the results will be analyzed and reported when the tests have been successfully completed.

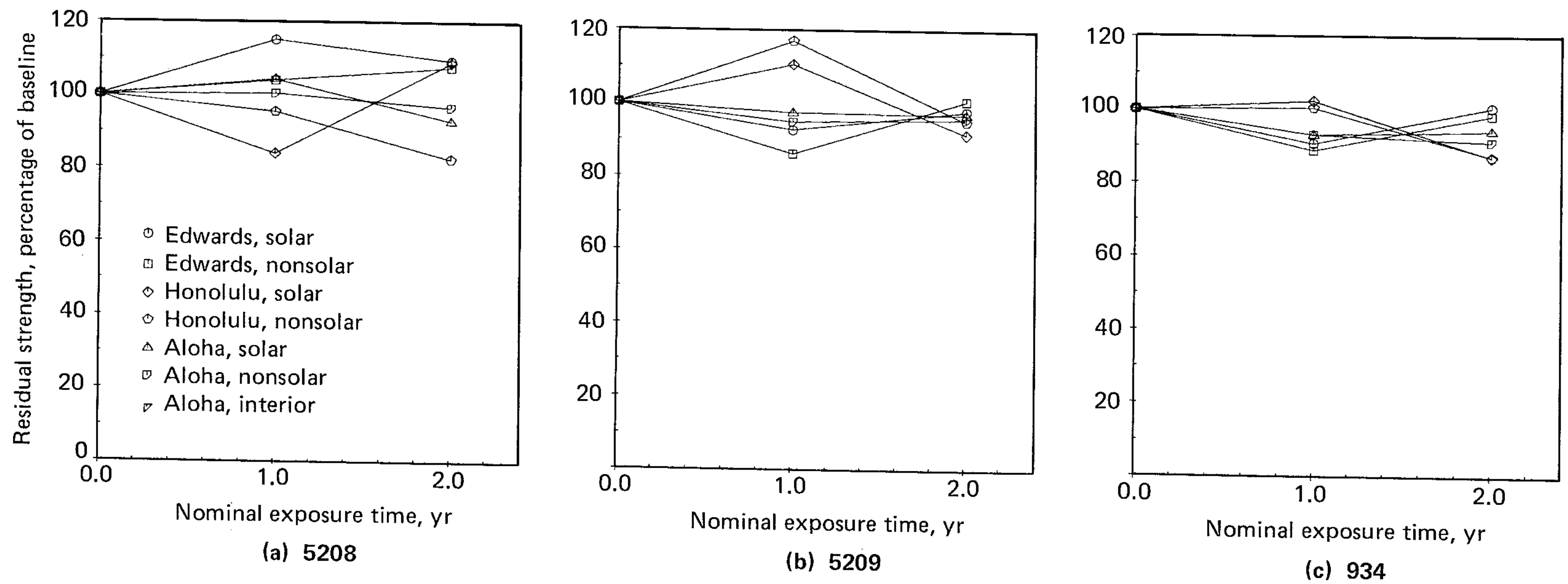


Figure 44. Individual Results, Short Beam Shear Dryout—82°C (180°F)

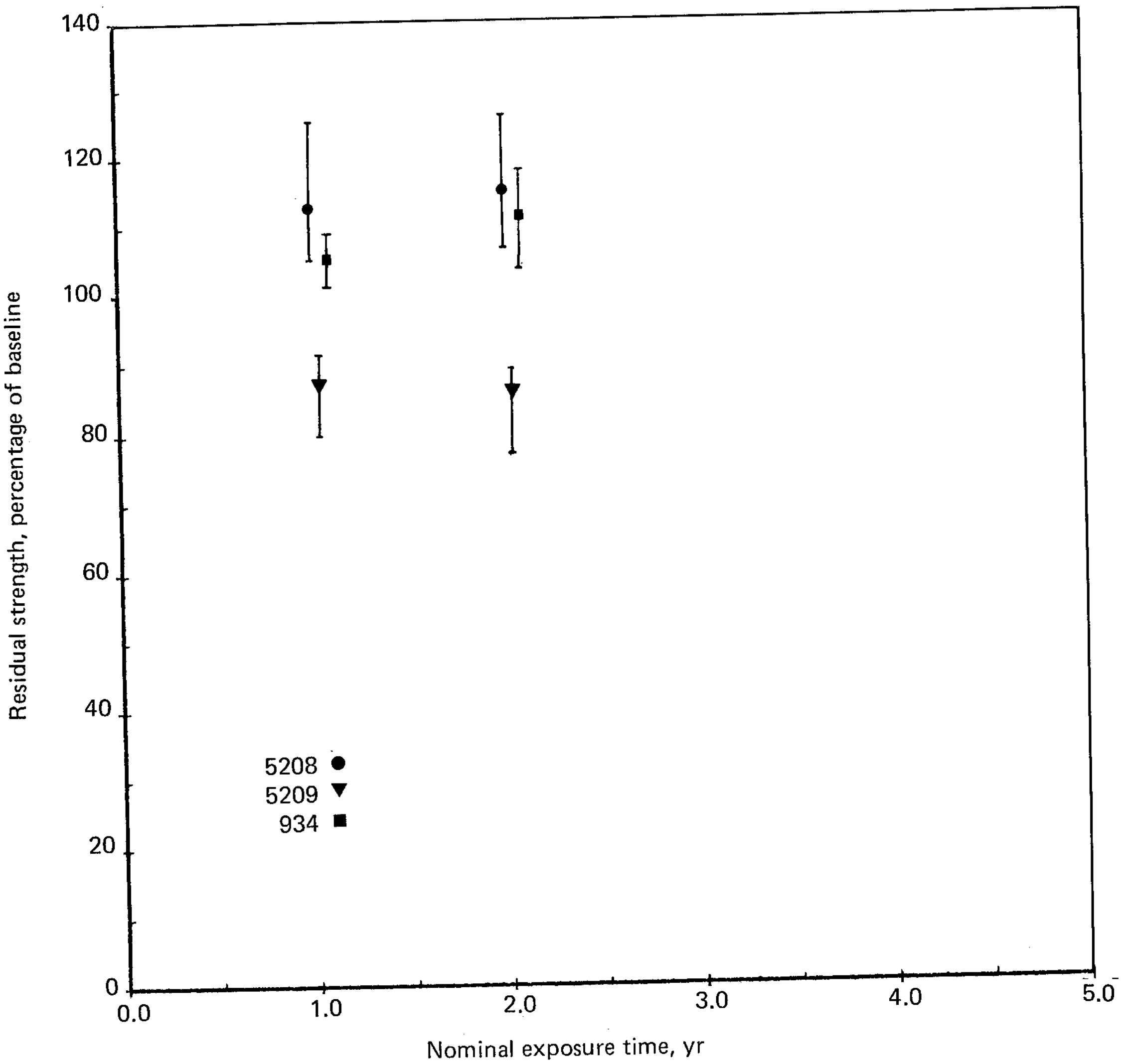


Figure 45. ±45-deg Tension, Stressed—82°C (180°F)

10.0 LABORATORY TEST RESULTS

10.1 BASELINE

Short Beam Shear—Baseline short beam shear testing was completed on T300/5208, T300/5209, and T300/934 at three different test temperatures. Five replicate specimens were tested at room temperature, 49°C (120°F), and 82°C (180°F) for each material system. Testing was performed in a Tinius-Olson 12-kip mechanical testing machine. Load deflection curves were recorded for the majority of the specimens using a D-2 Deflectometer. An American Instrument Company oven was used for all elevated temperature testing.

Individual specimen short beam shear test data are shown in Appendix B, Table B-1. Summary short beam shear strengths, as a function of test temperature, are shown in Figure 46. Each point shows the high, low, and average values for the group of five specimens. As expected, the Narmco T300/5208 and the Fiberite T300/934 systems show similar behavior while the Narmco T300/5209 [121°C (250°F)] cure system shows somewhat lower strengths at all temperatures.

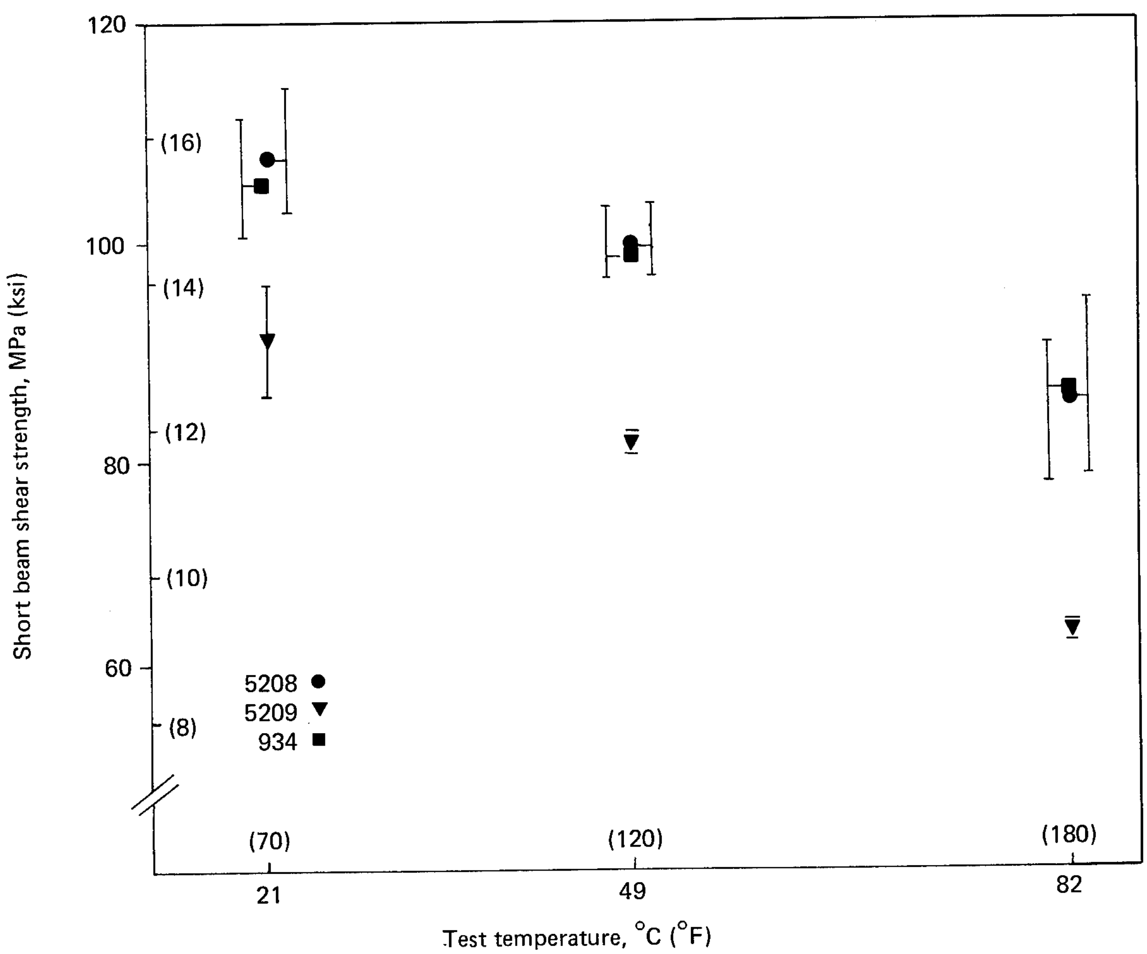


Figure 46. Baseline Short Beam Shear Strength Results

Flexure—Baseline flexure testing was performed in the same equipment used for short beam shear testing. Tabulated test data are shown in Appendix B, Table B-2. Summary flexure strength data, as a function of test temperature, are shown in Figure 47. In this case, strengths are reported as extreme fiber stresses. These are obtained using a laminated plate bending theory. For the layup considered,

$[0_2/\pm45/90_2]_S$ the bending stiffness, D_{11}, is

$$D_{11} = \frac{2}{3}\left[E_{xo}\frac{1}{1-V_{xyo}V_{yxo}}\left\{\left(\frac{t}{2}\right)^3-\left(\frac{t}{3}\right)^3\right\}\right.$$
$$+\ E_{x\pm45}\frac{1}{1-V_{xy\pm45}V_{yx\pm45}}\left\{\left(\frac{t}{3}\right)^3-\left(\frac{t}{6}\right)^3\right\}$$
$$\left.+\ E_{x90}\frac{1}{1-V_{xy90}V_{yx90}}\left(\frac{t}{6}\right)^3\right]$$

where t is specimen thickness, E_x are extensional moduli for the 0-, ±45-, and 90-deg directions, and V_{xy} are Poisson's ratios for the 0-, ±45-, and 90-deg directions.

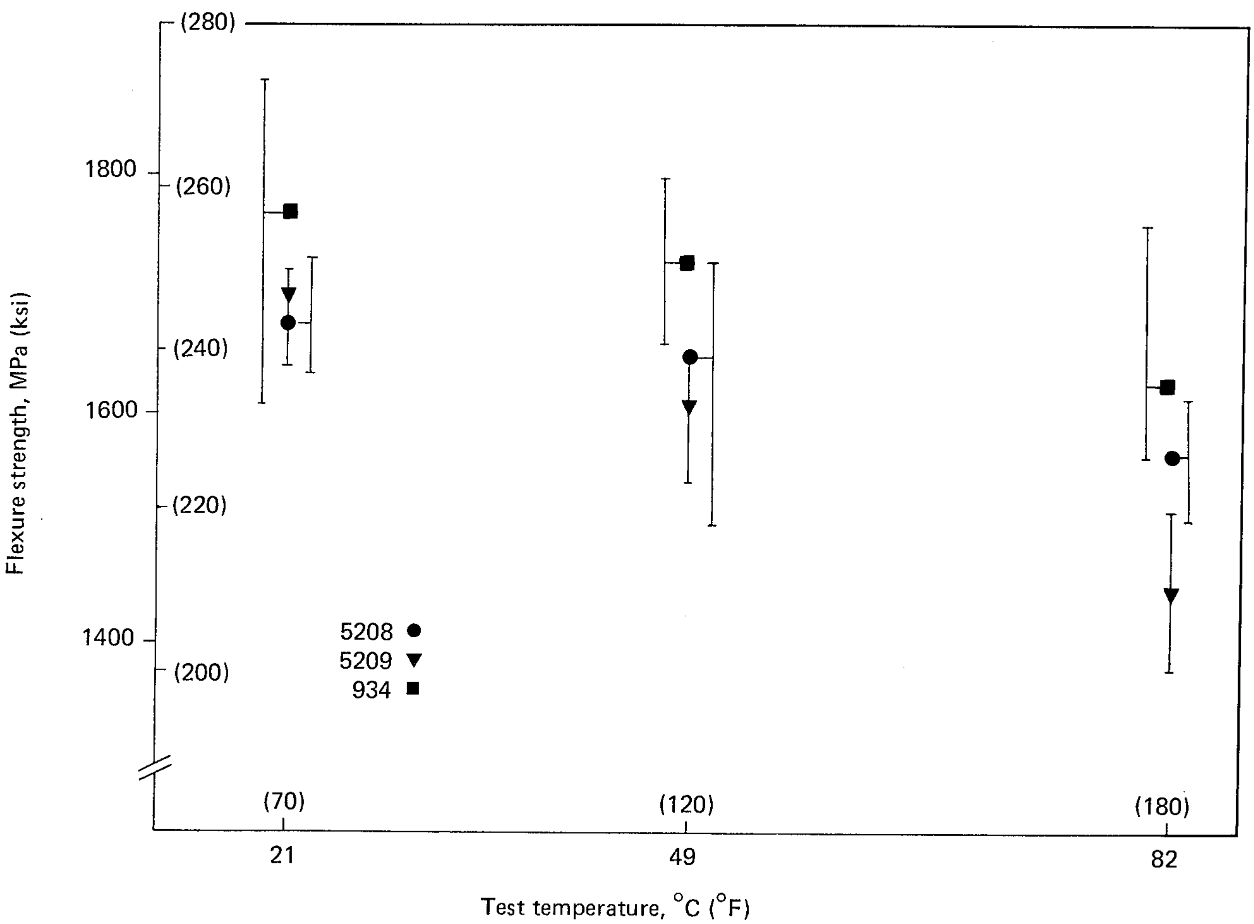


Figure 47. Baseline Flexure Strength Results

The maximum fiber stresses, σ_x, are computed assuming three point bending with the formula

$$\sigma_x = \frac{Plt\, E_{xo}}{8\, D_{11} w \left(1 - V_{xyo} V_{yxo}\right)}$$

where P is the ultimate load, l is the span, and w is the specimen width.

These computations do not consider nonlinear, temperature-dependent properties at this time. Edge effects and stress concentrations in the vicinity of the load points are also neglected. The values for the moduli and Poisson's ratios are given in Table 10.

Table 10. Fundamental Properties Used for Flexure Fiber-Strength Computations

MATERIAL	LAYUP	E_x, MPa (lb/in²) [1]	$1/1-V_{xy}V_{yx}$ [2]
5208	0	1.31×10^5 (1.90×10^7)	1.005
	±45	1.12×10^4 (1.63×10^6)	3.090
	90	1.65×10^4 (1.69×10^6)	1.005
5209	0	1.41×10^5 (2.05×10^7)	1.005
	±45	1.12×10^4 (1.63×10^6)	3.090
	90	1.55×10^4 (2.25×10^6) [3]	1.005
934	0	1.29×10^5 (1.87×10^7)	1.005
	±45	1.25×10^4 (1.81×10^6)	3.090
	90	1.68×10^4 (2.44×10^6)	1.005

Note:

[1] Values obtained from deflectometer room temperature data.

[2] Averages from design guide.

[3] Average of materials 5208 and 934.

Tension—Baseline tension testing was performed in an Instron model TTD-2109 test machine. Individual specimen test data are shown in Appendix B, Table B-3. A summary of the strength results as a function of temperature is given in Figure 48. The results represent three specimen test values at room temperature and at 82°C (180°F) and four specimen test values at 49°C (120°F). Other baseline specimens have been reserved for testing with strain gages rather than with an extensometer. One unexpected aspect of the results revealed in Figure 48 is that T300/5209 has substantially higher strength across the temperature range than has either T300/5208 or T300/934. If the T300/5209 strengths are abnormally high, this would explain the apparently low residual strengths reported for tension specimens in section 9.2.

Compression—Most of the baseline compression testing was performed in a Celanese compression fixture, although several room temperature tests were performed in an IITRI compression fixture during the comparison testing described in Reference 14. Loading was performed in a Tinius-Olson 12-kip mechanical testing machine. Load/cross head deflection curves were plotted for all tests.

Individual specimen test data are shown in Appendix B, Tables B-4, B-5, and B-6. A summary of the 0-deg compression strengths for all three materials is shown in Figure 49. The only notable aspects of these results are the somewhat low-strength values measured for T300/5208 and T300/5209 tested at 82°C (180°F). Average values for all baseline strength and glass transition temperature measurements appear in Tables 11, 12, and 13.

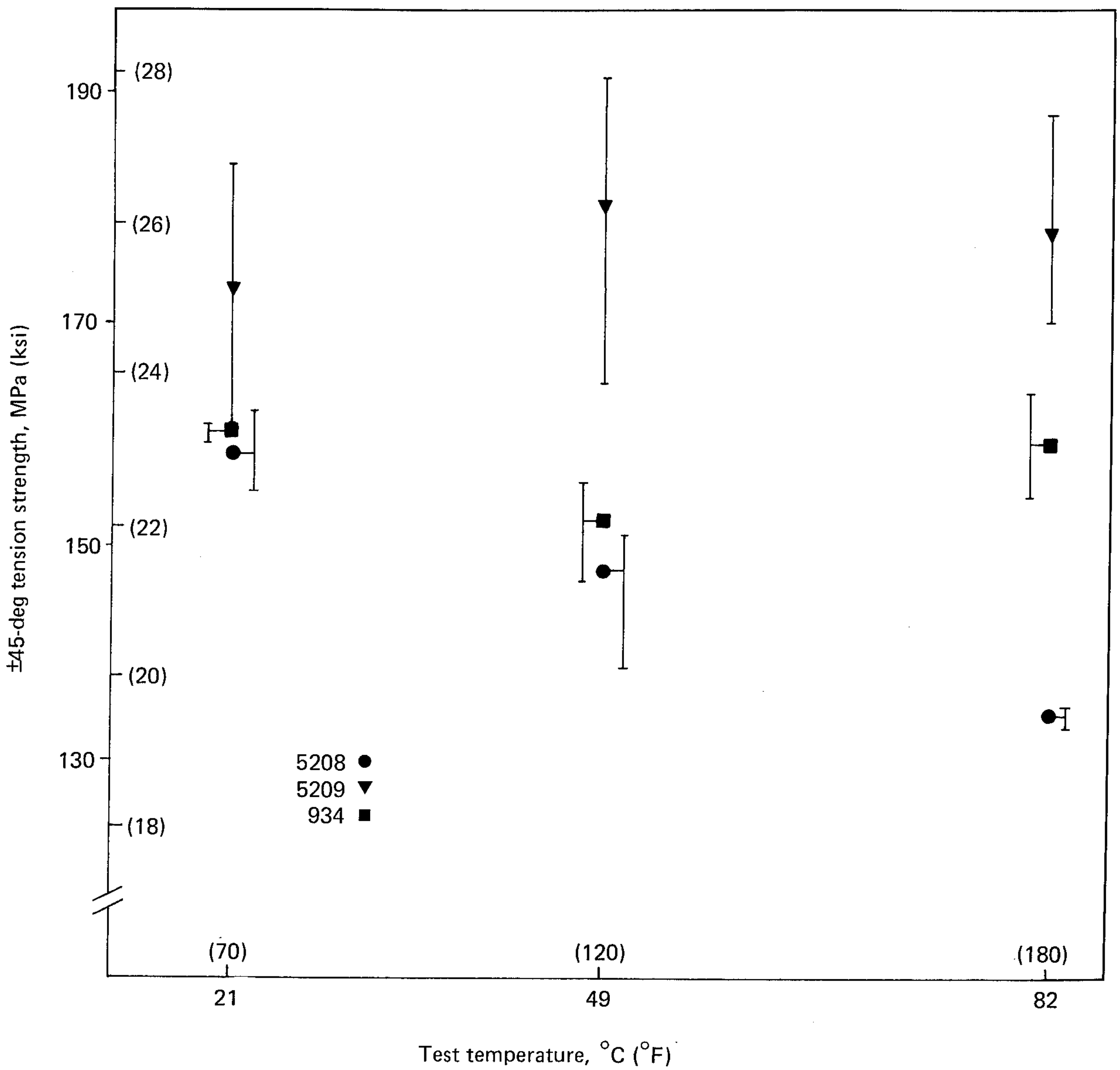


Figure 48. Baseline ±45-deg Tension Strength Results

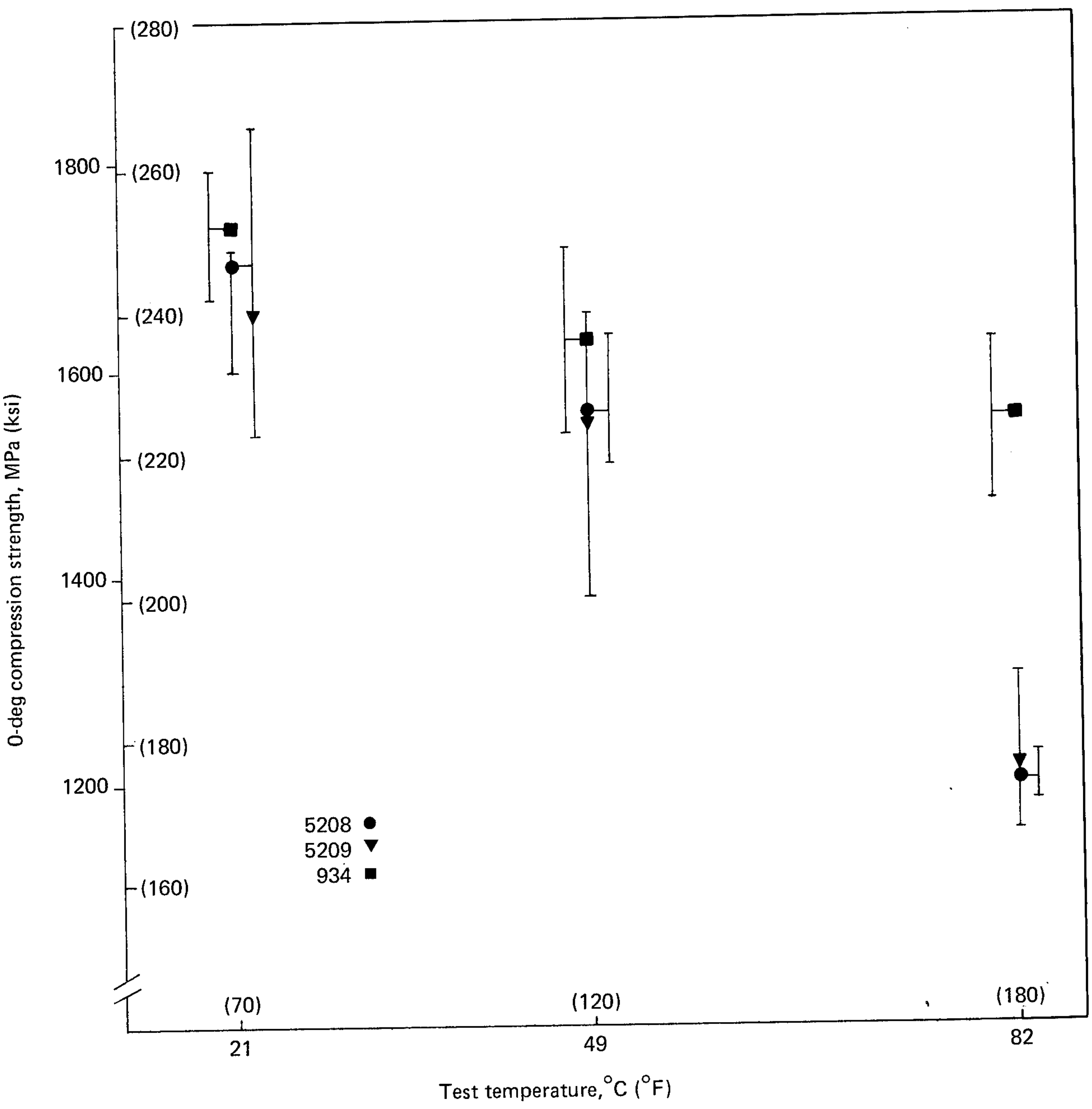


Figure 49. Baseline 0-deg Compression Strength Results

Table 11. T300/5208 Baseline and Effect of Temperature Results

SPECIMEN	STRENGTH, MPa (ksi)		
	ROOM TEMPERATURE	49°C (120°F)	82°C (180°F)
0-deg short beam shear	108.2 (15.70)	99.5 (14.44)	85.0 (12.33)
Flexure	1679.0 (243.63)	1649.0 (239.17)	1559.0 (226.16)
±45-deg tension	158.4 (22.98)	147.7 (21.43)	134.2 (19.46)
0-deg compression	1706.0 (247.44)	1561.6 (226.49)	1199.7 (174.01)
0-deg tension	1448.0 (210.02)		1543.8 (223.91)
Quasi-isotropic tension	335.6 (48.68)	324.6 (47.09)	340.4 (49.39)
90-deg compression	197.4 (28.63)	204.9 (29.73)	186.4 (27.04)
Quasi-isotropic compression	1048.9 (152.14)	919.5 (133.37)	867.6 (125.84)
Tg, °C (°F)	214 (417)		

Table 12. T300/5209 Baseline and Effect of Temperature Results

SPECIMEN	STRENGTH, MPa (ksi)		
	ROOM TEMPERATURE	49°C (120°F)	82°C (180°F)
0-deg short beam shear	91.1 (13.22)	80.9 (11.74)	63.5 (9.22)
Flexure	1699.0 (246.48)	1606.0 (232.97)	1443.0 (209.30)
±45-deg tension	173.2 (25.10)	180.7 (26.21)	178.1 (25.83)
0-deg compression	1657.0 (240.35)	1551.8 (225.07)	1206.0 (174.94)
0-deg tension	1723.0 (249.94)		1543.8 (223.91)
Quasi-isotropic tension	354.7 (51.45)	330.3 (47.91)	344.3 (49.93)
90-deg compression	209.6 (30.40)	179.6 (26.05)	158.5 (23.00)
Quasi-isotrpoic compression	573.5 (83.19)	538.8 (78.16)	475.5 (68.97)
Tg, °C (°F)	128 (262)		

Table 13. T300/934 Baseline and Effect of Temperature Results

SPECIMEN	STRENGTH, MPa (ksi)		
	ROOM TEMPERATURE	49°C (120°F)	82°C (180°F)
0-deg short beam shear	106.1 (15.39)	99.1 (14.38)	86.2 (12.51)
Flexure	1770.0 (256.78)	1730.0 (250.94)	1626.0 (235.85)
±45-deg tension	160.2 (23.23)	152.3 (22.09)	158.9 (23.06)
0-deg compression	1738.0 (252.08)	1624.4 (235.60)	1554.0 (225.42)
Quasi-isotropic tension	386.8 (56.11)	371.3 (53.86)	324.9 (47.13)
90-deg compression	190.8 (27.68)	193.1 (28.01)	173.5 (25.17)
Quasi-isotropic compression	900.2 (130.56)	856.4 (124.22)	816.4 (118.41)
Tg, °C (°F)	205 (401)		

10.2 EFFECT OF TIME ALONE

To date, specimens have been tested after nominal 1-year and 2-year time exposure. The short beam shear and flexure individual specimen data appear in Appendix B, Tables B-7 through B-10. Residual strength results for 1 year are presented in Table 14, and for 2 years, in Table 15. Most of the residual strengths do not fall below 92% of baseline. The only configuration to fall below this level was the 2-year T300/934 short beam shear tested at 82°C (180°F) that dropped to 87.3% of baseline strength. The scatter of the individual specimen test data for this configuration was not large (C_v = 0.048). This specimen group lost a greater percentage of weight during time alone than was lost by any of the other groups.

Glass transition temperature (T_g) measurements were made after 1 year of time alone exposure, only. Changes from baseline values were within 2%, so no T_g measurements were made at 2 years.

Specimen weight change measurements were made for all specimens before exposure and after completion of exposure. All specimen groups lost weight during exposure. The weight loss can be attributed to moisture desorption. Results are given in Tables 14 and 15 and in Figure 50. The T300/5208 flexure and the T300/5209 short beam shear 1-year specimens experienced more weight loss than the respective 2-year specimens. The other specimen configurations experienced equal or greater weight loss from 1-year to 2-year exposure.

10.3 EFFECT OF MOISTURE AND EFFECTS OF TIME AND STRESS ON WET SPECIMENS

Moisture gain data was tracked through 121 days of exposure using individual specimen weighings. Normalized weight change data of specimens exposed to 95% RH at 49°C (120°F) are shown in Figure 51. The data represents three individual flexure specimens from each of the three material systems. Generally, the data follow predictable moisture diffusion trends. The T300/5209 specimens behaved differently from both of the 177°C

Table 14. 1-yr Time Alone Residual Strength and Weight Change Results*

SPECIMEN	ROOM TEMPERATURE	82°C (180°F)	WEIGHT CHANGE, %	CLASS TRANSITION TEMPERATURE, °C (°F)
Short beam shear				
5208	93	100	−0.103	
5209	92	101	−0.051	
934	97	100	−0.092	
Flexure				
5208	93	100	−0.176	218 (425)
5209	100	100	−0.078	125 (257)
934	93	100	−0.165	205 (401)

*Residual strength data reported as a percentage of baseline strength at the respective temperature. Each data point represents five specimen tests.

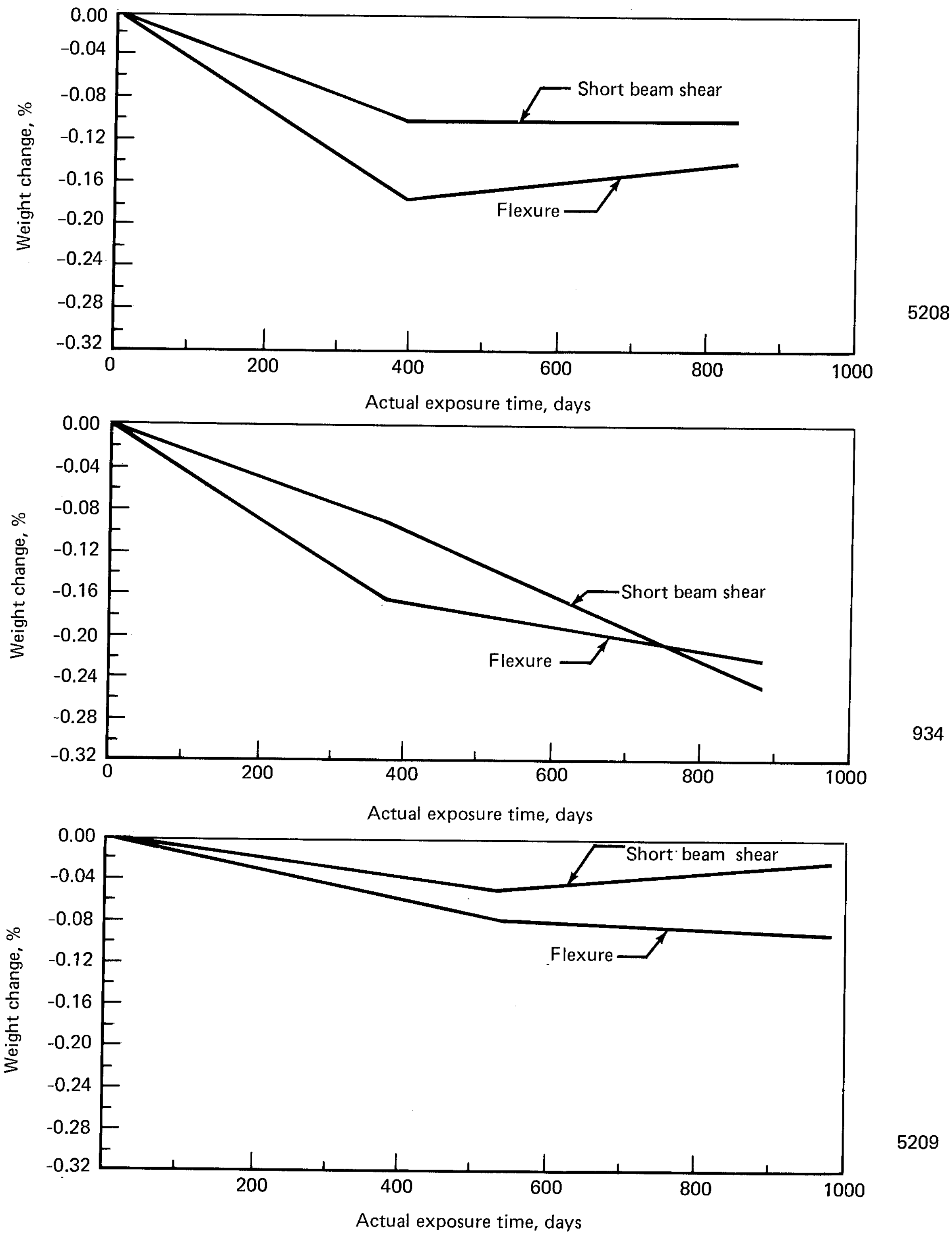


Figure 50. Time Alone Weight Change Results

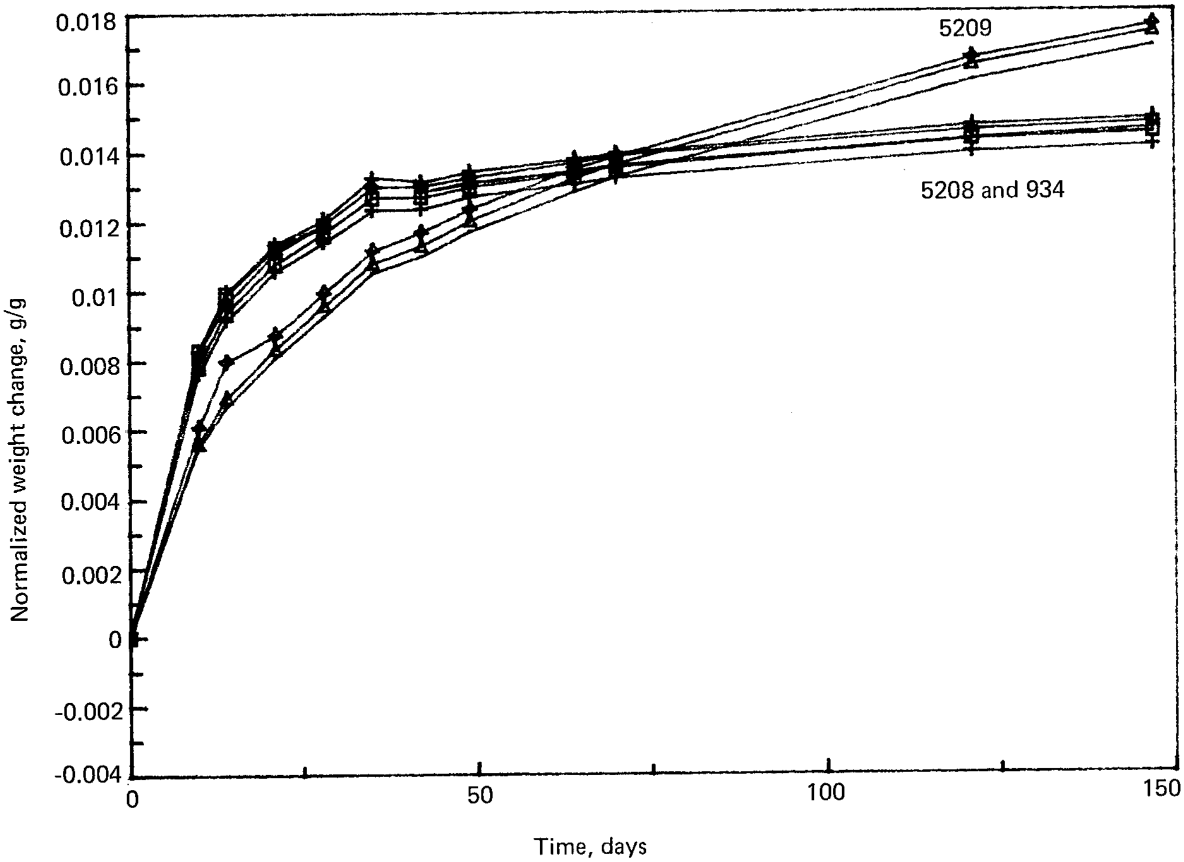


Figure 51. Normalized Weight Change for 95% Relative Humidity Exposure

Table 15. 2-yr Time Alone Residual Strength and Weight Change Results*

SPECIMEN	ROOM TEMPERATURE	82°C (180°F)	WEIGHT CHANGE, %
Short beam shear			
5208	99.6	96.2	–0.103
5209	93.6	94.9	–0.026
934	96.6	87.3	–0.248
Flexure			
5208	96.5	97.7	–0.141
5209	97.7	102.2	–0.093
934	103.0	98.6	–0.222

*Residual strength data reported as a percentage of baseline strength at the respective temperature. Each data point represents five specimen tests.

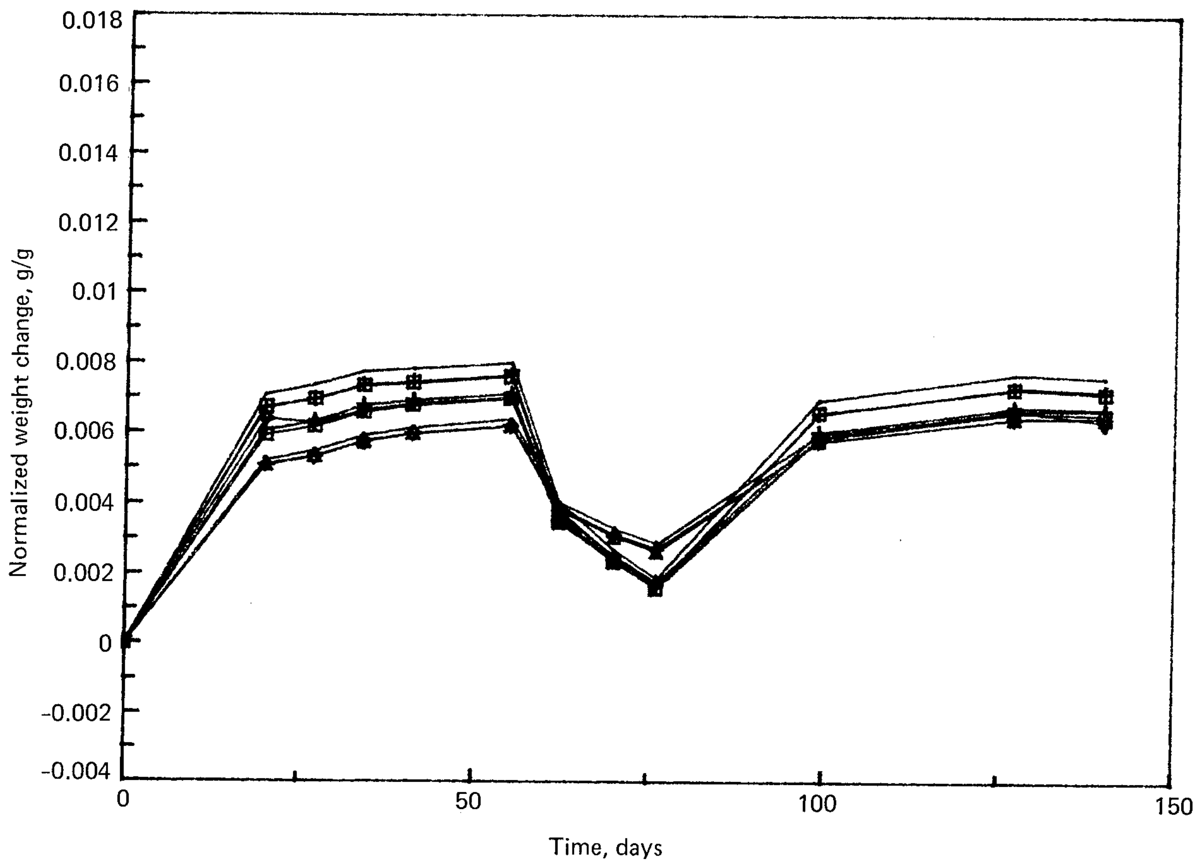


Figure 52. Normalized Weight Change for 75% Relative Humidity Exposure

(350°F) curing systems. Initially, the T300/5209 specimens absorbed moisture at a lower rate. After 121 days of exposure, however, they had absorbed more moisture than the other two systems and were still gaining. The T300/5208 and T300/934 specimens were still picking up moisture but at a much lower rate.

Normalized weight changes for specimens exposed to 75% relative humidity are shown in Figure 52. Although there are no individual specimen anomalies, the entire set of data showed a dramatic desorption during the middle of the exposure period. An investigation indicated that either the lid on the 75% RH desiccator was not resealed properly following the weighing on the 55th day of exposure, or it was bumped during other activities around the desiccator. The air-circulating oven used to maintain the 49°C (120°F) exposure temperature then rapidly altered the makeup of the glycerin/water solution. As the water evaporated, the resultant solution became more biased towards the glycerin, thus producing a lower RH condition even after the lid was correctly sealed. Therefore, the old solution was discarded and replaced with new stock. As a precaution, the solutions for the other exposures also were replaced to maintain the assigned moisture levels.

Weight change measurements for 60% RH are shown in Figure 53, and 40% RH, in Figure 54. Both of these sets of specimens reached equilibrium moisture content, and neither showed any significant anomalies. The 40% RH measurements show a slight decline after peaking at about 55 days of exposure. This may be due to a lesser degree of the same problem experienced with the 75% specimens. Individual materials are not shown on Figures 52 through 54 because the 95% exposure is the only condition where a clear difference can be observed.

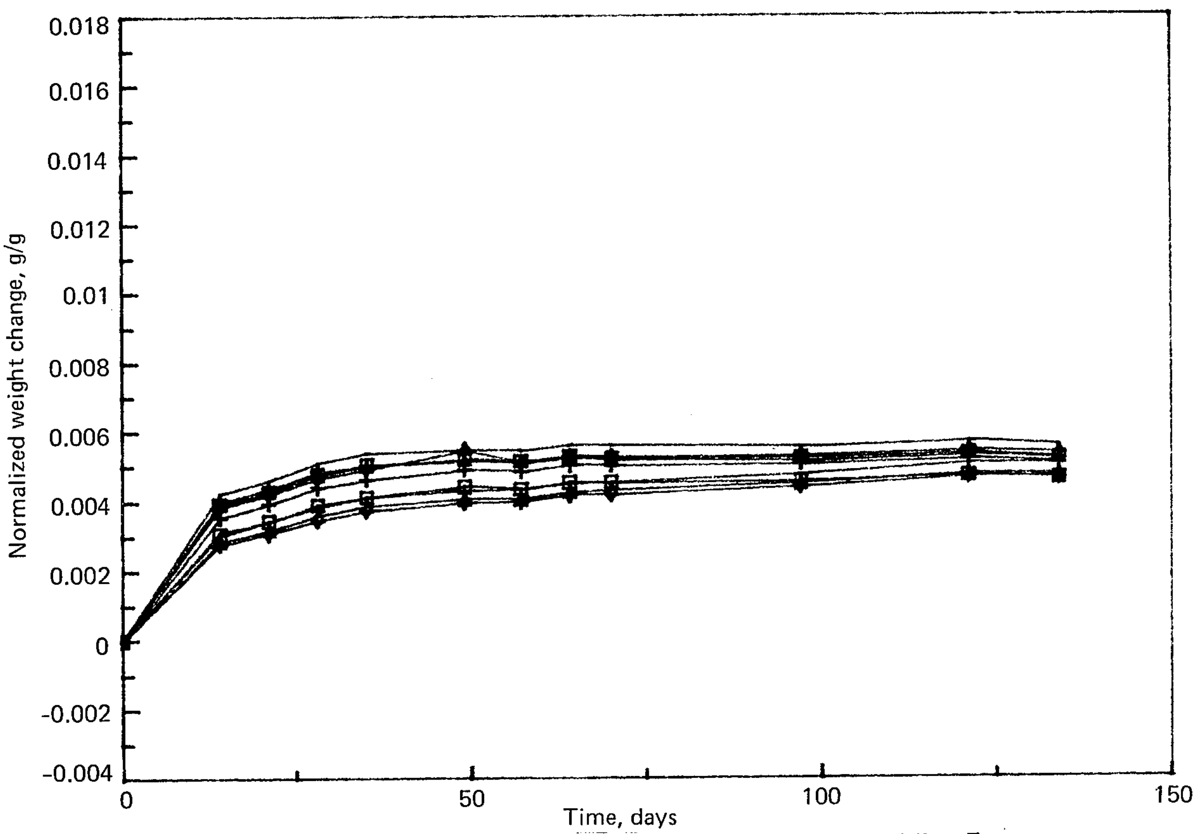


Figure 53. Normalized Weight Change for 60% Relative Humidity Exposure

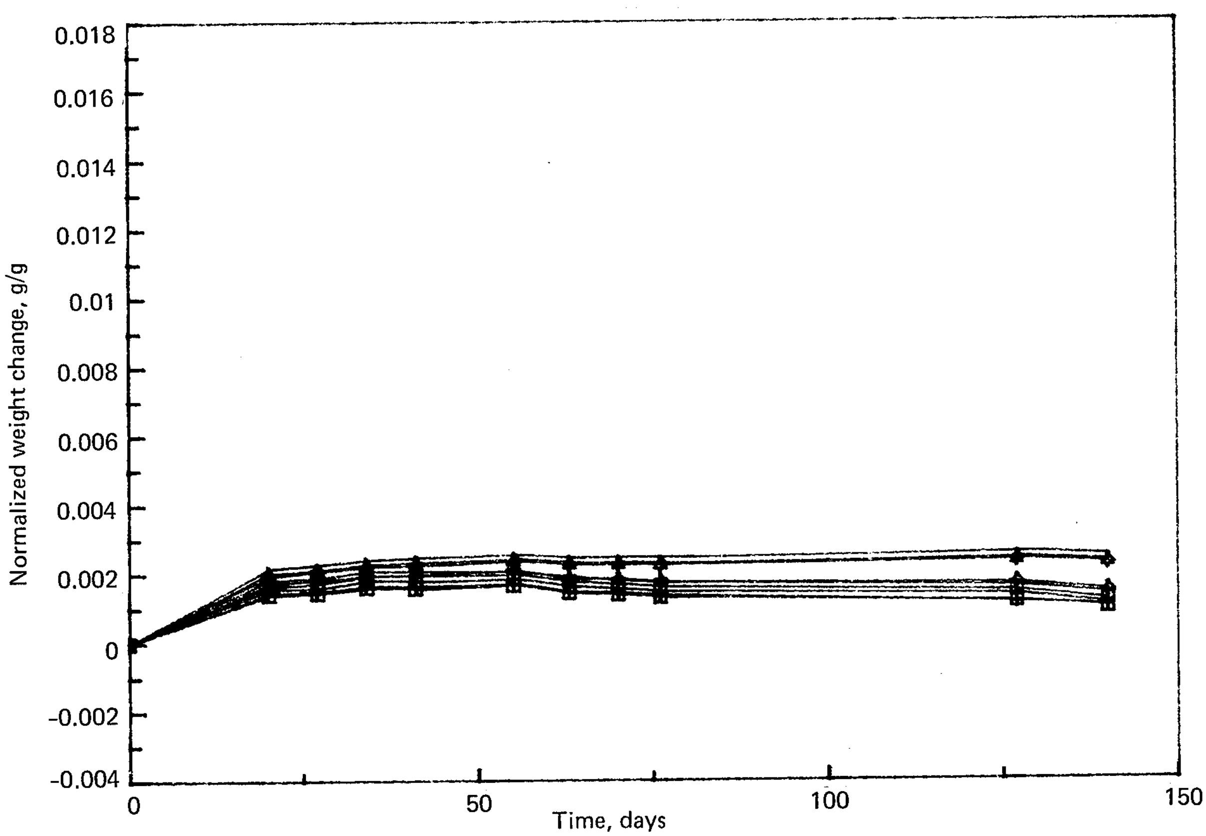


Figure 54. Normalized Weight Change for 40% Relative Humidity Exposure

Table 16 shows the observed moisture content in the specimens at the time of mechanical test. Figure 55 portrays the same data. All three material systems are shown, and with one exception, the data are relatively consistent at humidities below 75%. The figure also illustrates a 0% moisture content for specimens at approximately 25% humidity, indicating that this was representative of the original (dry drum storage) environment. Finally, the moisture contents at 95% or condensing humidity are higher than a linear extrapolation of the lower values would indicate.

The test plans called for one set of specimens to be tested when an equilibrium weight gain was achieved. Two other sets were planned for testing following various times at equilibrium. Individual mechanical test data for the first set of specimens appear in Reference 12. Unlike time alone specimens, these tests showed significant strength changes. Residual strength results, as a percentage of baseline strengths, are presented in Table 17.

All three material systems show a general decrease in short beam shear strength with increasing humidity exposure. As expected, the strength reductions are more pronounced at 82°C (180°F) than they are at room temperature. Again, the two 177°C (350°F) curing systems behaved similarly, while the 121°C (250°F) curing system reacted differently.

Flexure strengths also changed because of humidity exposure but, as expected, the strength reductions were less severe with the more fiber-dominated specimen. At room temperature, some strengths actually increased.

One could infer from Table 17 that a severe moisture problem could exist on any or all of the material systems shown; however, a 95% or condensing humidity exposure at 49°C (120°F) is considerably more severe than real-world conditions. Although the test may be useful as an indicator, the absolute numbers achieved may not be realistic. A 75% humidity condition at 49°C (120°F) is considered the upper end of real-world environment.

Table 16. Observed Percentage of Moisture Content After Humidity Conditioning

TYPE OF SPECIMEN	RELATIVE HUMIDITY			
	40%	60%	75%	95%
Short beam shear	0.24	1.10 [1]	0.74	1.34
	0.28	0.57	0.81	1.32
Flexure	0.21	0.58	0.82	1.44
5208 AVG	0.24	0.57	0.79	1.37
Short beam shear	0.30	0.50	0.78	— [2]
	0.33	0.63	0.92	—
Flexure	0.34	0.57	0.84	1.84
5209 AVG	0.32	0.57	0.85	1.84
Short beam shear	0.25	0.56	0.85	1.59
	0.33	0.65	0.95	1.71
Flexure	0.22	0.53	0.80	1.45
934 AVG	0.27	0.58	0.87	1.58

Note:

[1] Apparently erroneous value was disregarded.

[2] Never weighed—reexposure in work.

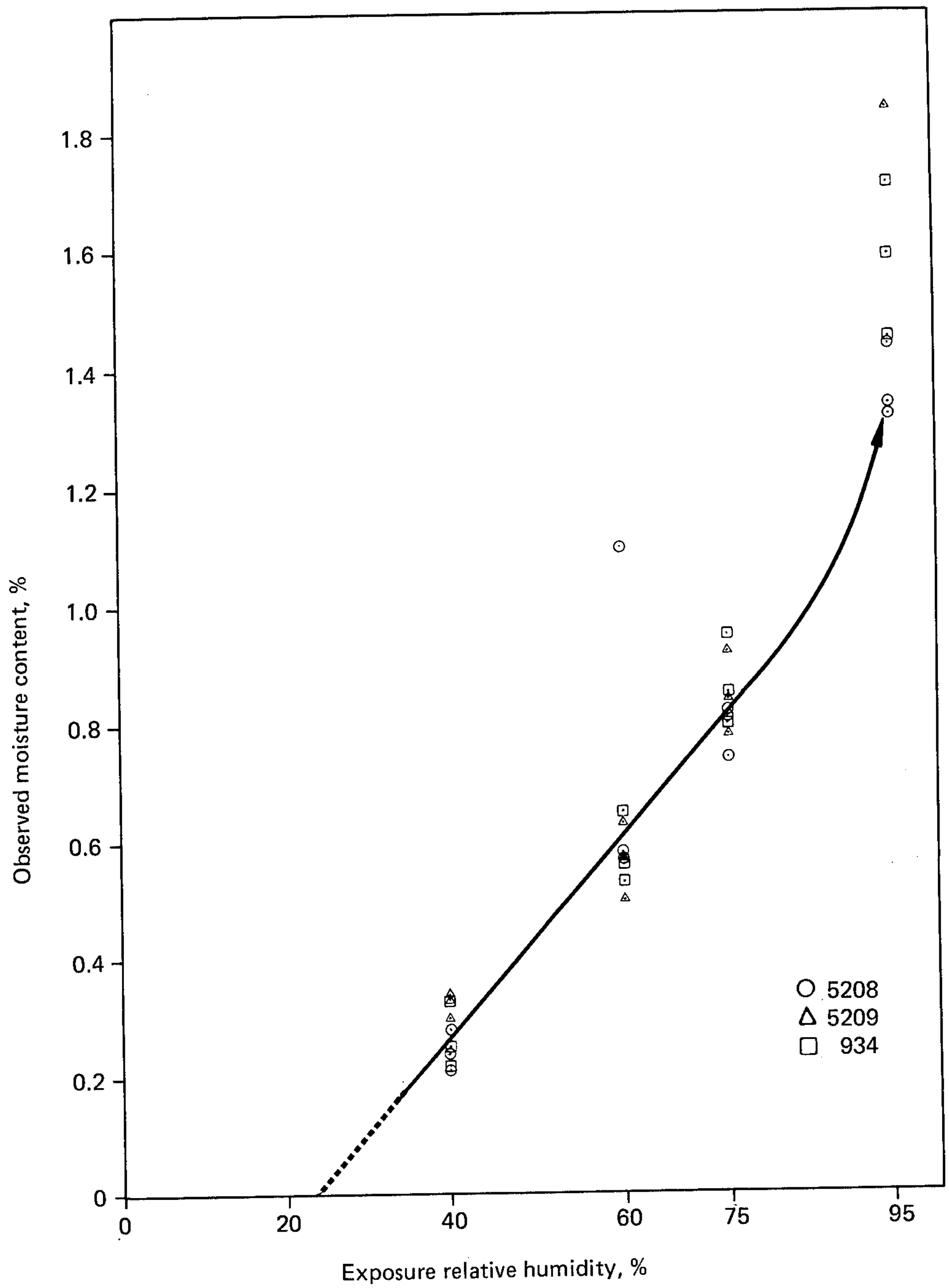


Figure 55. Moisture Content as a Function of Humidity

Table 17. Summary of Residual Strength After Humidity Exposure

PROPERTY	EXPOSURE HUMIDITY, %	PERCENTAGE OF BASELINE STRENGTHS					
		5208		5209		934	
		ROOM TEMPERATURE	82°C (180°F)	ROOM TEMPERATURE	82°C (180°F)	ROOM TEMPERATURE	82°C (180°F)
Short beam shear strength	40	94	95	93	86	96	90
	60	88	85	83	72	91	80
	75	88	81	84	68	89	75
	95	80	66	*	30	80	57
Flexure strength	40	98	96	102	96	101	97
	60	99	92	105	88	100	91
	75	97	91	101	77	101	86
	95	94	84	86	41	94	76

*Due to a testing error these specimens tested at 82°C (180°F); a replacement set is being conditioned.

Note:

Each data point represents five specimen tests.
82°C (180°F) values ratioed against 82°C (180°F) dry baseline.

Most airplane structure also is better represented by the flexure specimen than it is by the matrix-dominated short beam shear specimen. Finally, it should be noted that Boeing model 737 spoilers using the T300/5209 system have been performing well in actual service for over 6 years (ref. 4). The T300/5209 moisture weight gain data show a definite behavior change in the 95% exposure condition when compared with the other three humidity levels. For some humidities, the T300/5209 absorbs the same or possibly even less moisture than the 177°C (350°F) curing systems. The original plan called for the T300/5209 specimens to be tested at a moisture-equilibrium condition. They were, however, tested along with the other two systems when it appeared that this system was not reaching equilibrium in this exposure.

10.4 WEATHEROMETER TESTING

During exposure in the weatherometer, the group of specimens designated for residual strength testing after 2-year exposure was tracked for weight change. The average results for the three materials for unpainted specimens are presented in Figure 56. The two 177°C (350°F) cure materials, T300/5208 and T300/934, lost weight from the outset of exposure, but the 121°C (250°F) cure T300/5209 experienced a slight increase before beginning to lose weight. There are two possible explanations for these behavioral differences. First, the recorded weights shown in these figures represent a total of absorbed moisture weight gain and degraded resin weight loss. It is possible that the T300/5209 system was absorbing significantly greater amounts of moisture that more than compensated for the resin weight loss. Second, both 177°C (350°F) curing systems use MY720 for their base resin. Earlier Boeing R&D work has shown that MY720 is particularly susceptible to UV degradation. The T300/5209 system does not use MY720 and, therefore, may be less susceptible.

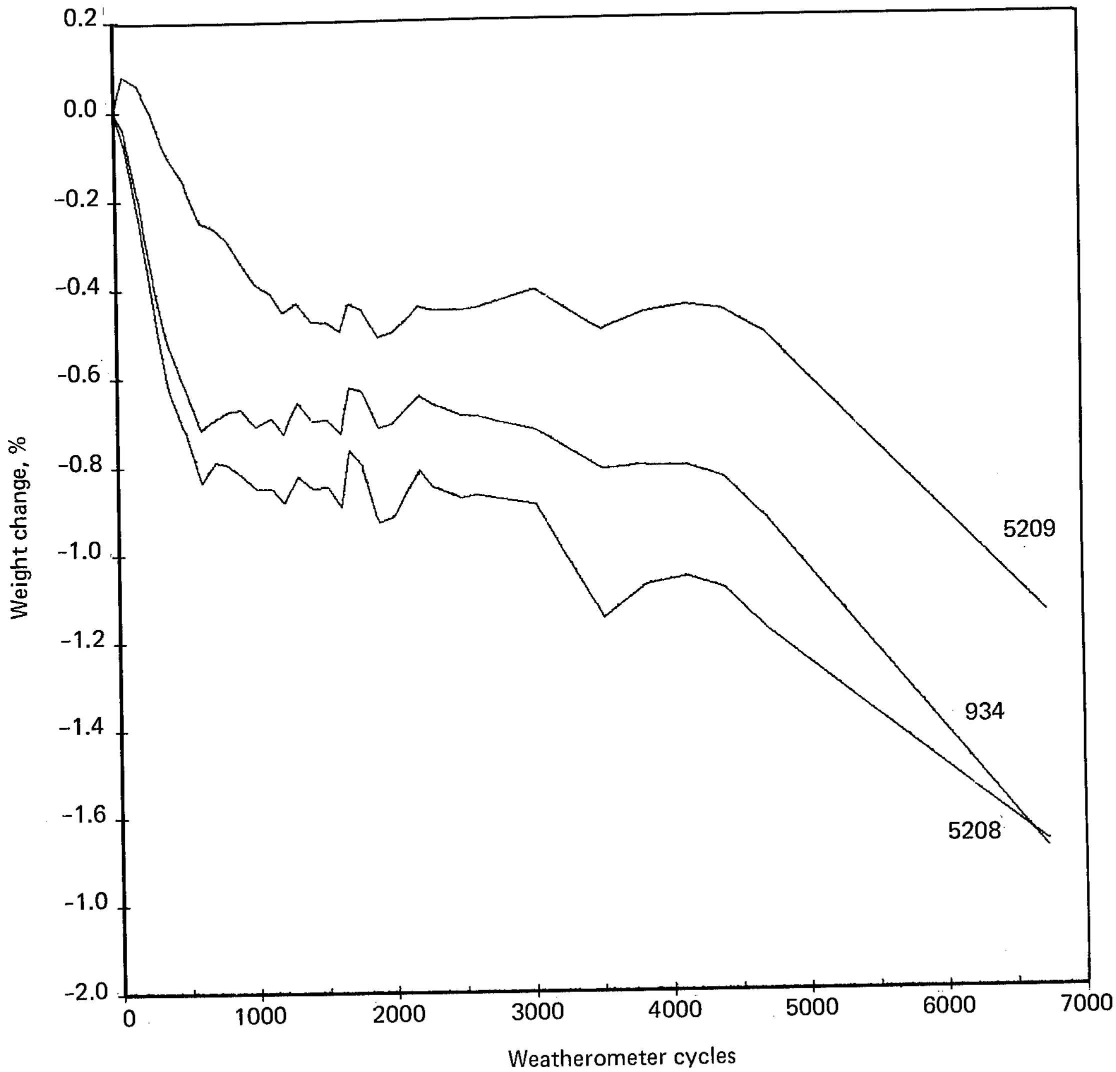
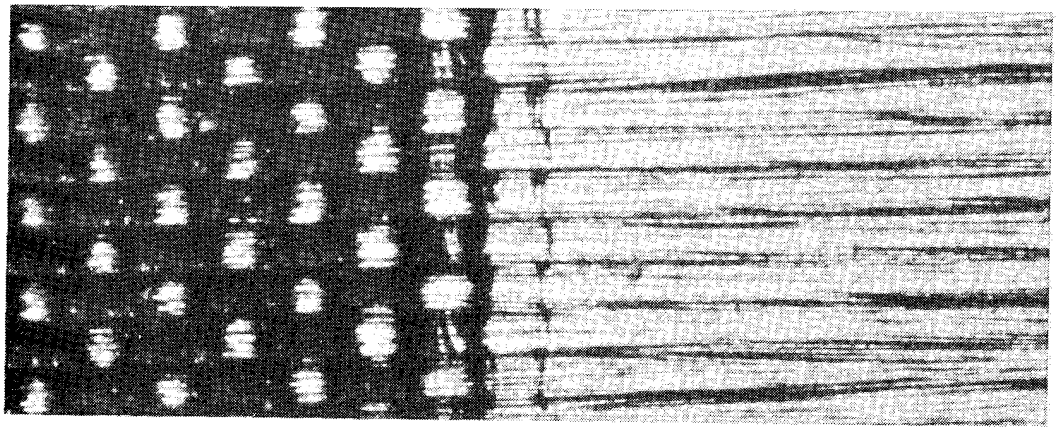


Figure 56. Weights of Unpainted Weatherometer Specimens

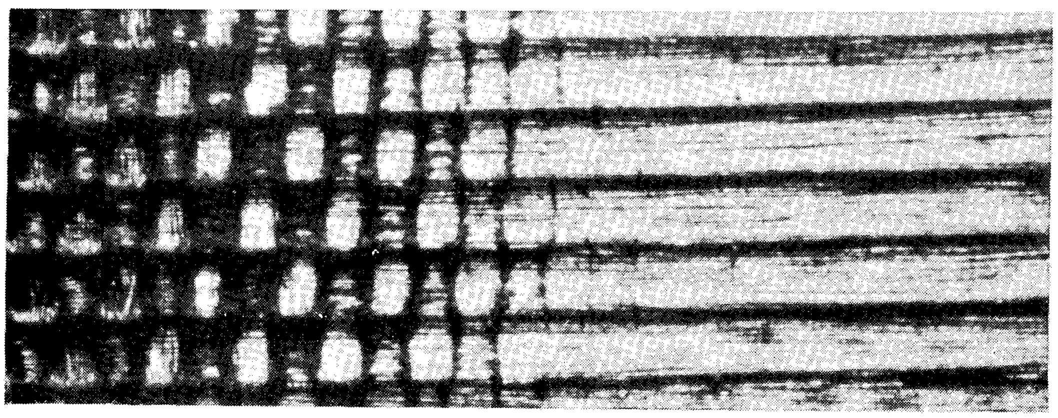
The large weight decreases ultimately experienced by the unpainted weatherometer specimens are caused by surface matrix erosion as visible in Figure 57. This magnified view of the surfaces exposed to UV radiation shows the exposed graphite fibers on the right and the undegraded peel ply texture on the left. The undegraded portion was protected from UV radiation by the specimen-holding fixture.

Apparently paint also helps protect the surface material from UV degradation and erosion. Figure 58 shows the percentage of weight change for painted specimens during exposure. Large weight decreases did not appear until 2000 weatherometer cycles when the specimens experienced a lower weight loss rate than the unpainted specimens experienced. The painted specimen weight loss rates have no appreciable difference with respect to material type. The amount of weight lost by those painted specimens might be attributed to chalking and erosion of the paint.

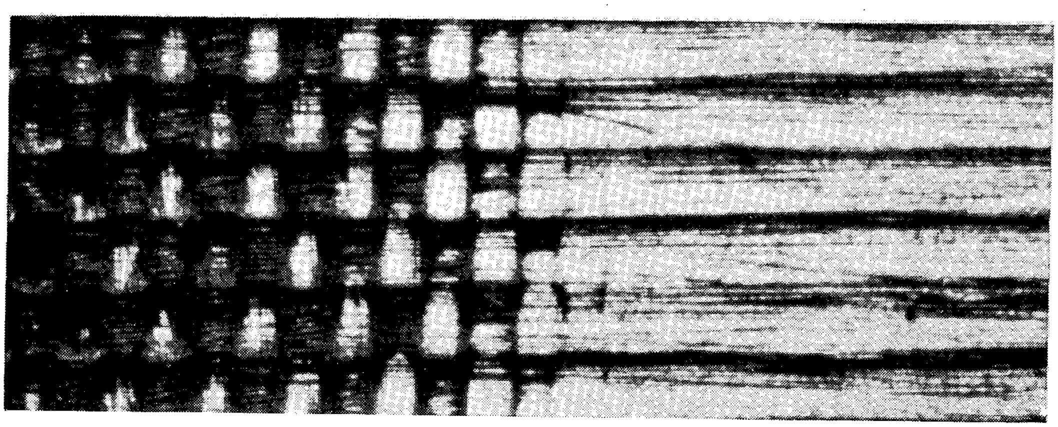
Individual physical property measurements and residual failure loads for 6-month and 1-year specimens appear in Appendix B, Tables B-11, and B-12. Residual strength testing was performed according to the test procedures outlined in section 6.6 for flexure testing.



5208



5209



934

Figure 57. Surfaces of Nominal 6-mo Weatherometer-Exposed Specimen

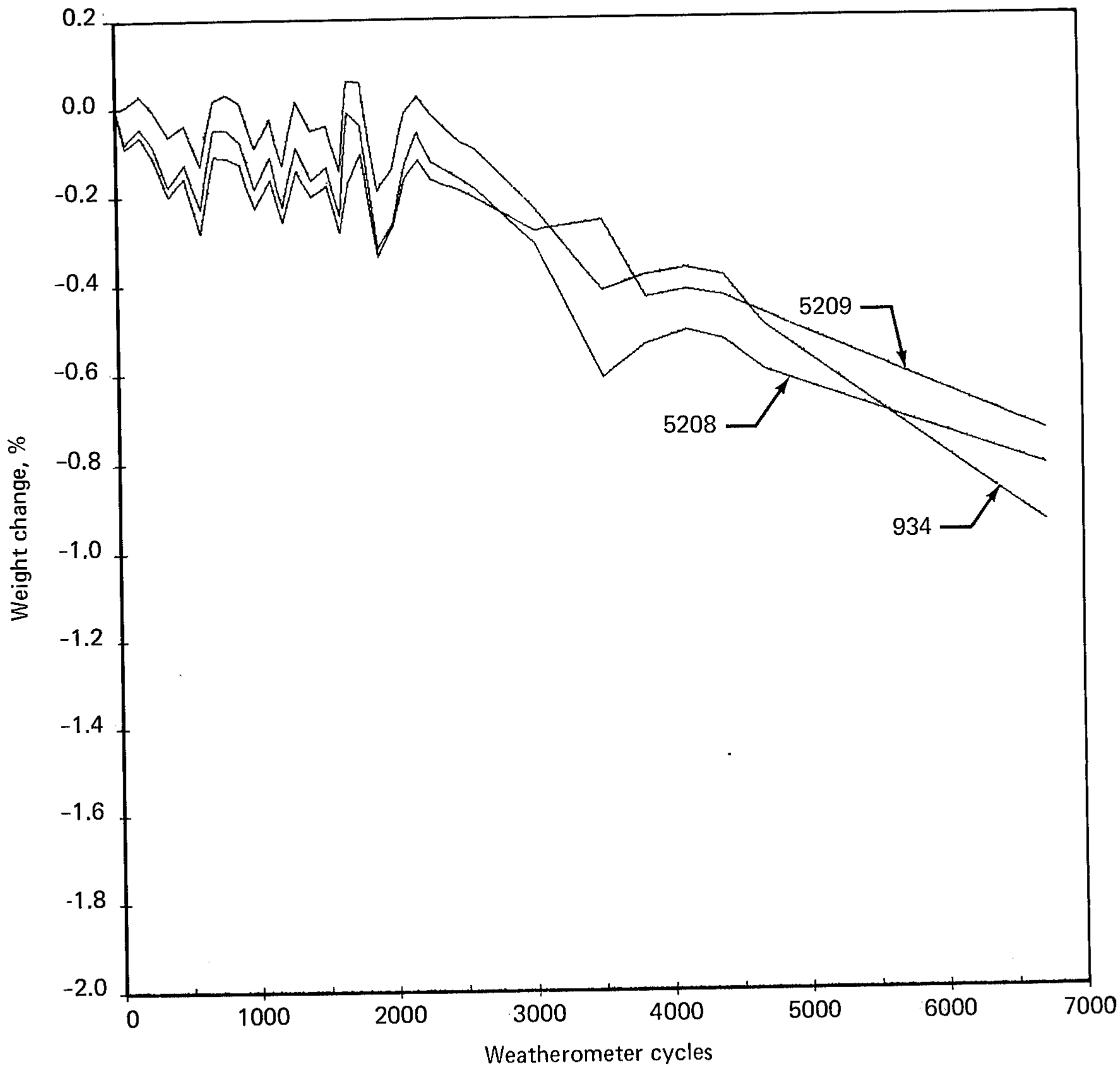


Figure 58. Weights of Painted Weatherometer Specimens

Residual strength and T_g test results for 6-month exposure appear in Table 18, and for 1-year exposure, in Table 19. The flexure strength results for the painted and unpainted specimens are plotted in Figure 59. There is no evidence of significant strength reductions, and most measured strengths were greater than baseline. The unpainted specimens were only marginally weaker than the painted specimens.

10.5 GROUND-AIR-GROUND

After 3200 GAG cycles in the Webber chamber, specimens of T300/5208, T300/5209, and T300/934 showed definite weight gains as illustrated in Figures 60, 61, and 62. The T300/5208 system absorbed the most moisture, and the T300/5209 system absorbed the least. All three systems gained weight, reached a plateau, then resumed the weight-gain process. This led to a concern that a freeze/thaw damage mechanism was gradually cracking the specimens. Several photomicrographs were taken of these specimens to look for possible cracks, but no macrocracking or microcracking was visible. Figure 63 shows one of these micrographs.

Table 18. Weatherometer 6-mo Nominal Exposure

MATERIAL	RESIDUAL FLEXURE STRENGTHS,* %		GLASS TRANSITION TEMPERATURE, °C (°F)	
	ROOM TEMPERATURE	82°C (180°F)	6-mo	CHANGE FROM BASELINE
5208 Painted	112	116	— —	— —
Unpainted	111	105	207 (405)	-7 (-112)
5209 Painted	—	93	— —	— —
Unpainted	—	100	131 (268)	+3 (+6)
934 Painted	—	99	— —	— —
Unpainted	—	95	193 (379)	-12 (-22)

*Residual strength data reported as a percentage of baseline strength at the respective temperatures. Each data point represents five specimen tests.

Table 19. Weatherometer 1-yr Nominal Exposure

MATERIAL	RESIDUAL FLEXURE STRENGTHS,* %		GLASS TRANSITION TEMPERATURE, °C (°F)	
	ROOM TEMPERATURE	82°C (180°F)	1 yr	CHANGE FROM BASELINE
5208 Painted	89.9	115.5	203 (398)	-11 (-19)
Unpainted	94.4	92.6	207 (405)	-7 (-12)
5209 Painted	—	117.3	116 (241)	-12 (-21)
Unpainted	—	103.0	121 (250)	-7 (-12)
934 Painted	—	108.7	195 (383)	-10 (-18)
Unpainted	—	99.6	196 (384)	-9 (-17)

*Residual strength data reported as a percentage of baseline strength at the respective temperatures. Each data point represents five specimen tests.

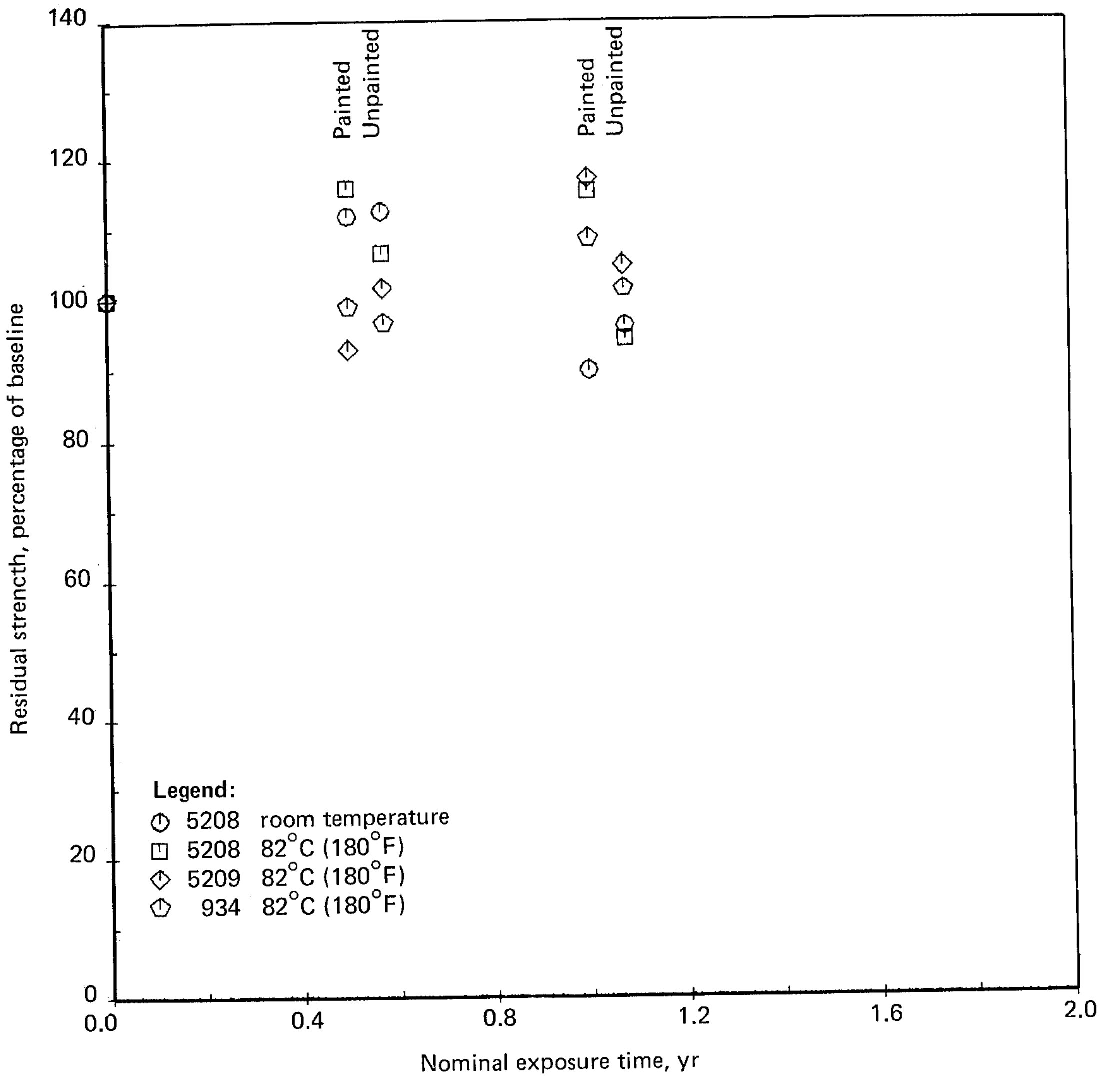


Figure 59. Weatherometer Flexure Strength Results

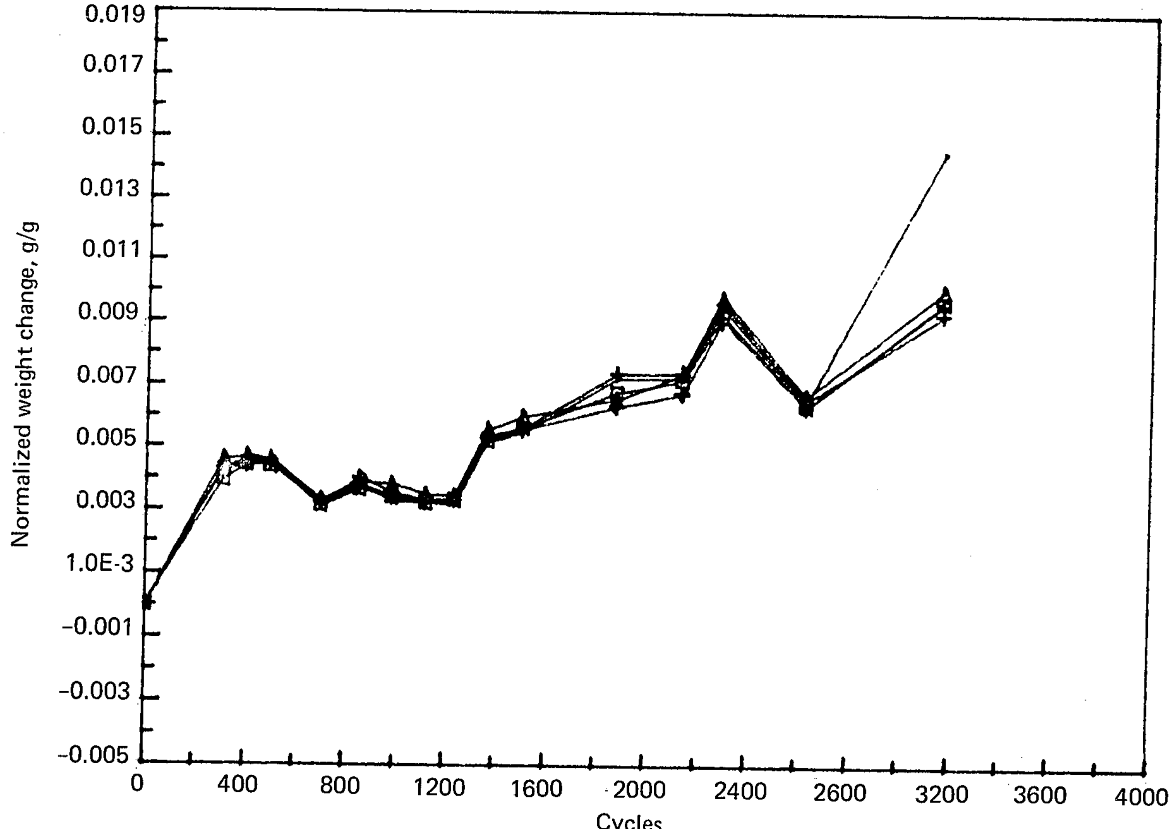


Figure 60. Weight Change of Unpainted 5208 as a Function of Ground-Air-Ground Cycles

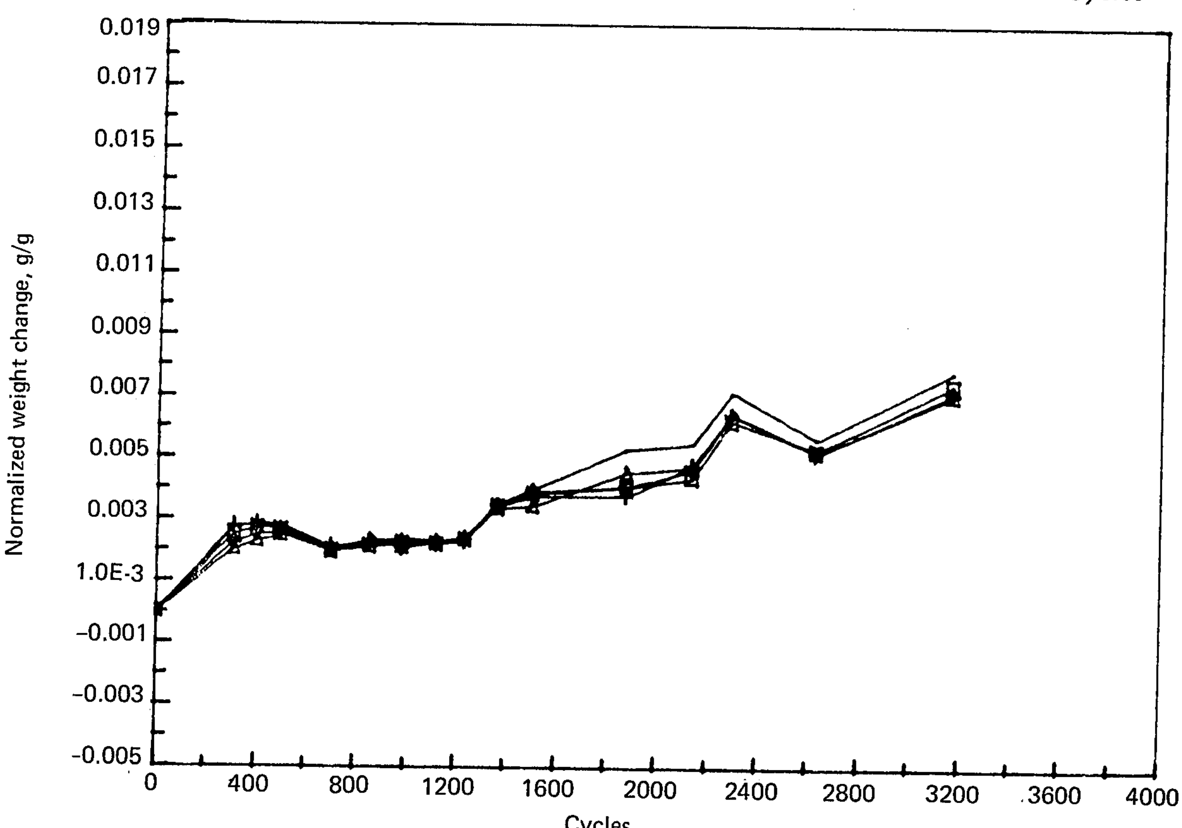


Figure 61. Weight Change of Unpainted 5209 as a Function of Ground-Air-Ground Cycles

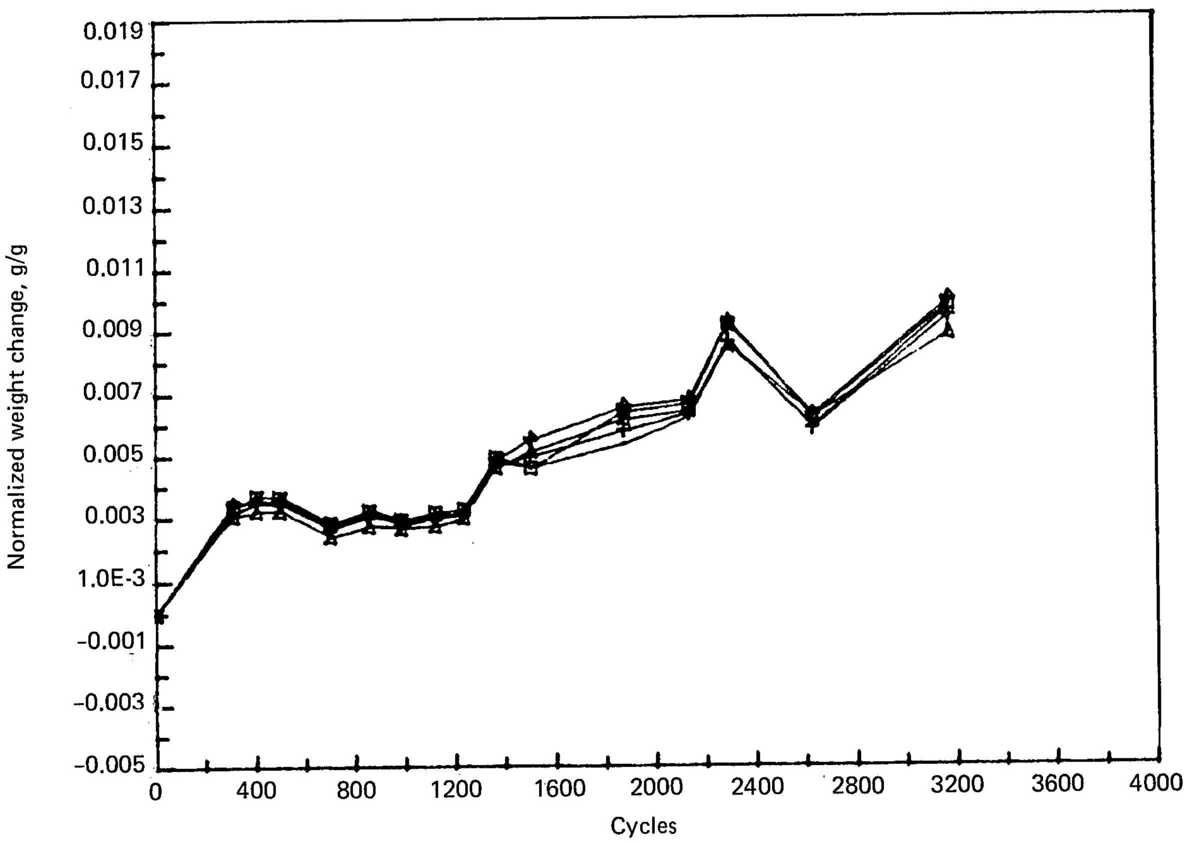


Figure 62. Weight Change of Unpainted 934 as a Function of Ground-Air-Ground Cycles

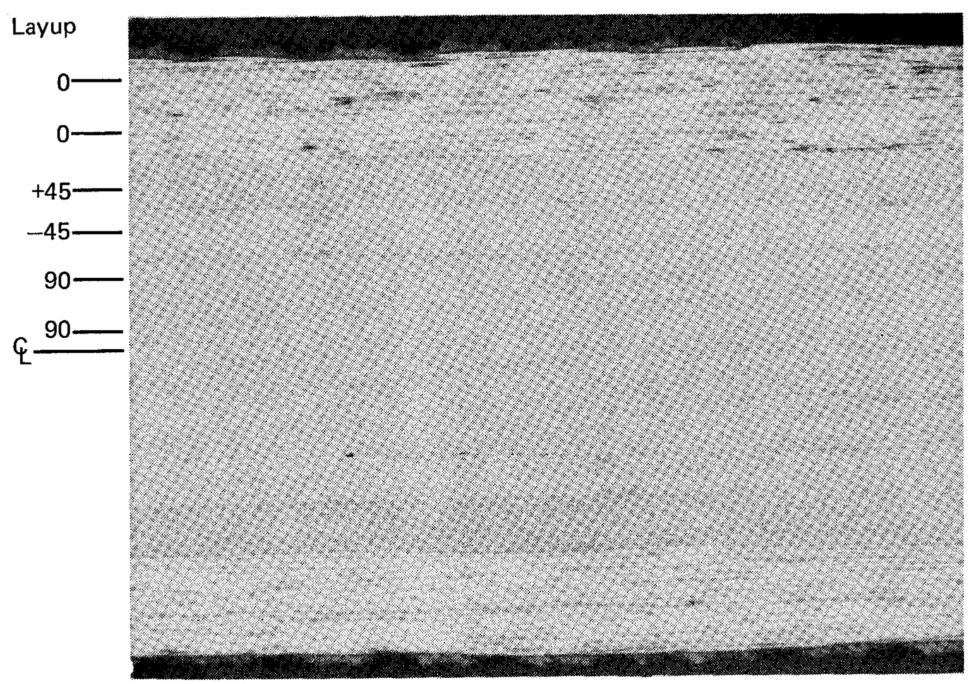


Figure 63. Flexure Specimen Edge After Nominal 6-mo Simulated Ground-Air-Ground Cycling

A second possible explanation for the gain-plateau-gain weight pattern concerns the exposure chamber itself. Chamber reliability has been poor. Periodic scheduled and unscheduled maintenance has caused several prolonged shutdowns. The exact environment experienced by the specimens during these shutdowns is uncertain because maintenance procedures have been far more extensive than originally anticipated. The continued practical availability of this chamber is currently being investigated.

After 6 months of exposure, a set of flexure and a set of short beam shear specimens were removed from the chamber and tested for residual strength. The physical properties and test data for these specimens are given in Reference 13.

Testing was performed according to the procedures outlined in section 6.6. The results appear in Table 20. Testing at 82°C (180°F) generally produced a greater strength loss than testing at room temperature with one exception, the flexure strength of T300/5208. The measured moisture contents of the GAG specimens ranged from 0.7 to 1.0%. Most of the observed strength reductions can be attributed to the presence of the moisture.

Table 20. 6-mo Ground-Air-Ground Residual Strength Results*

SPECIMEN	TEST TEMPERATURE	
	ROOM TEMPERATURE	82°C (180°F)
Short beam shear		
5208	88.4	79.3
5209	79.9	61.7
934	86.1	67.3
Flexure		
5208	80.4	83.4
5209	83.1	72.6
934	87.9	79.9

*Residual strength data reported as a percentage of baseline strength at the respective temperature. Each data point represents five specimen tests.

11.0 CONCLUSIONS

The scope of this contract covers many environmental exposure conditions from real-world sites to controlled laboratory chambers. Many environmental factors including RH and moisture, temperature, UV radiation, and surface coating are being considered simultaneously. This complexity will require careful correlation of data. Much of the lab data and most of the long-term data are yet to be collected. Comments on test data obtained to date are:

Long-term environmental exposure residual tests:

- Exposed ±45-deg tensile specimens of T300/5208 and T300/934 generally experienced higher strengths than baseline. Tensile strengths for T300/5209 tested at 82°C (180°F) were lower than baseline. The ±45-deg tensile baseline strengths for T300/5209, however, may have been high.

- Two-year environmental exposure had a perceptible effect on flexure strength. Solar exposure and hydraulic fluid are apparently strength-degrading effects.

- Strength losses in short beam shear specimens are apparently related to moisture content. Short beam shear specimens that were dried prior to test were generally stronger than undried (wet) specimens.

For the laboratory exposure residual strength tests:

- Flexure specimens from weatherometer, moisture, and to a lesser extent Webber chamber/GAG exposures, generally retained baseline strengths.

- In some cases, short beam shear specimens exposed in moisture and Webber chambers had substantially less strength than baseline. The strength losses are apparently related to moisture content.

12.0 REFERENCES

1. Brower, G. L.: Applications of Graphite Composites on the 757 and 767. Boeing paper presented at the Second Industry Review of the NASA ACEE Composite Programs, Seattle, Washington, August 11-13, 1980.

2. Chovil, D. V.; Harvey, S. T.; McCarty, J. E.; Desper, O. E.; Jamison, E. S.; and Snyder, H.: Advanced Composite Elevator for Boeing 727 Aircraft. Volume I - Technical Summary. NASA CR-3290, 1981.

3. Dexter, H. B.: Composite Components on Commercial Aircraft. NASA TM-80231, 1980.

4. Hoffman, D. J.: 737 Graphite Composite Flight Spoiler Flight Service Evaluation. NASA CR-159362, 1980.

5. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165641, 1978.

6. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165642, 1978.

7. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165643, 1978.

8. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165644, 1978.

9. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165645, 1979.

10. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165646, 1979.

11. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165647, 1979.

12. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165648, 1979.

13. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165649, 1980.

14. Hoffman, Daniel J.: Environmental Exposure Effects on Composite Materials for Commercial Aircraft. NASA CR-165765, 1981.

APPENDIX A

RESULTS OF LONG-TERM EXPOSURE RESIDUAL TEST

TABLES

*Table A-1. Summary of Results—Wellington, New Zealand, 1-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension	94.2 102.8 112.2	87.9 100.7 118.5	90.8 104.7 118.4
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension SBS Dryout	81.8 101.6 118.7 98.8	67.0 78.2 88.1 100.9	74.6 91.1 109.5 99.3
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^0$ Tension	.65 .68 .64	.39 .38 .39	.51 .56 .49
Weight Loss During Dryout	SBS Dryout$^+$	1.00	.50	.87

$^+$Dryout oven overheat to 177°C (350°F), 2 days

Notes:

* These specimens exposed for 508 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-2. Summary of Results—Wellington, New Zealand, 1-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS	86.6	87.0	87.8
	Flexure	106.2	98.9	93.8
	Compression	94.6	99.1	100.4
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS	88.1	69.9	73.4
	Flexure	96.8	78.9	92.5
	Stressed Tension	125.4++	87.0	105.7
	Compression	73.0	87.1	85.6
	SBS Dryout	104.2	97.6	97.3
Weight Change Data Percent Gain + Percent Loss -	SBS	.60	.43	.67
	Flexure	.61	.40	.56
	Stressed Tension	.57	.42	.61
Weight Loss During Dryout	SBS Dryout+	.92	.50	.84

+Dryout oven overheat to 177°C (350°F), 2 days.

++Gripping tab slippage.

Notes:

* These specimens exposed for 507 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-3. Summary of Results—Air New Zealand, 1-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	92.6 104.2	87.4 102.2	90.6 101.7
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{\circ}$ Tension SBS Dryout	93.2 96.8 124.8 103.4	73.1 80.4 --- 99.7	77.7 93.9 117.3 96.6
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Stressed $\pm 45^{\circ}$ Tension	.58 .65 .15	.54 .36 ---	.58 .52 .49
Weight Loss During Dryout	SBS Dryout+	.83	.57	.70

+Dryout oven overheat to $177^{\circ}C$ ($350^{\circ}F$), 2 days.

Notes:

* These specimens exposed for 516 days, 2681 flight hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-4. Summary of Results—Air New Zealand, 1-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	90.3 105.7	85.6 104.7	88.2 98.8
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension SBS Dryout	89.0 103.4 114.2 78.4	73.8 99.7 --- 100.9	75.9 94.9 112.6 98.2
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^0$ Tension	.60 .66 .64	.36 .28 ---	.55 .49 .57
Weight Loss During Dryout	SBS Dryout+	.53	.60	.94
+Dryout oven overheat to 177^{0}C (350^{0}F), 2 days.				

Notes:

* These specimens exposed for 516 days, 2681 flight hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-5. Summary of Results—Air New Zealand, 1-yr Interior Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension Compression	95.5 107.4 118.9 89.4	102.8 106.7 120.5 101.5	94.7 101.5 123.4 96.5
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension Stressed Tension Compression	76.1 99.1 102.6 110.1 79.2+	71.7 96.4 83.3 87.4 89.6	77.9 90.5 113.7 105.9 78.1
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^0$ Tension Stressed Tension	.43 .50 .41 .55	.35 .25 .37 .40	.49 .49 .50 .56

+Gripping tab slippage.

Notes:

* These specimens exposed for 516 days, 2681 flight hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-6. Summary of Results—Honolulu, Nominal 1-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure ±45° Tension SBS Dryout+	89.4 102.7 107.5 95.5	82.4 101.7 104.9 117.0	87.0 105.6 103.5 100.5
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure ±45° Tension	87.5 111.1 98.2	74.6 89.4 80.8	73.4 103.2 94.0
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Tension	0.270 0.063 0.045	-0.028 -0.077 0.073	0.294 0.178 0.162
Weight Loss During Dryout	SBS Dryout	.98	.62	.90
+SBS Dryout specimens incorrectly tested at R.T.				

Notes:

* These specimens exposed for 398 days.

** Residual strength data based on baseline tests at the respective temperatures

*Table A-7. Summary of Results—Honolulu, Nominal 1-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Compression	95.0 108.2 83.5	83.7 107.7 105.8	80.4 106.6 97.9
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Compression Stressed Tension	85.1 111.0 77.4++ 112.5	73.4 95.8 79.0+ 80.4+	72.9 102.1 80.2 106.1
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Stressed Tension	0.296 -0.014 0.310	0.067 -0.011 0.088	0.306 0.218 0.324
Weight Loss During Dryout	SBS Dryout	0.86	0.58	-0.97

+Average of two measurements.

++Gripping tab slippage.

Notes:

* These specimens exposed for 398 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-8. Summary of Results—Honolulu, Nominal 2-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension	52.5 96.4 109.2	78.9 99.3 112.7	79.9 103.4 106.0
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension SBS Dryout	81.7 96.6 112.6 82.7	65.6 82.9 78.5 95.2	70.1 93.7 106.9 87.3
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^{0}$ Tension	.315 .239 -.095	-.026 -.152 -.188	.346 .171 .030
Weight Loss During Dryout	SBS Dryout	1.16	.98	1.28

Notes:

* These specimens exposed for 740 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-9. Summary of Results—Honolulu, Nominal 2-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	85.7 105.7	78.0 108.3	80.3 96.7
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Stressed Tension SBS Dryout	80.9 100.8 126.3 109.1	64.3 84.2 77.3 91.8	63.7 98.6 118.3 87.2
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Stressed Tension	.423 .332 .204	.231 .083 .090	.532 .394 .211
Weight Loss During Dryout	SBS Dryout	1.20	.93	1.34

Notes:

* These specimens exposed for 740 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-10. Summary of Results—Aloha Airlines, Nominal 1-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	87.4 106.6	84.6 110.3	85.2 105.3
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension SBS Dryout	87.9 110.7 125.5 104.4	72.7 87.5 --- 97.4	77.4 101.8 106.2 93.11
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^0$ Tension	0.387 0.409 -0.484	0.278 0.095 ---	0.500 0.400 0.013
Weight Loss During Dryout	SBS Dryout	0.98	0.84	1.11

Notes:

* These specimens exposed for 1942 flight hours, 5760 flight cycles, 394 days on aircraft #N73721.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-11. Summary of Results—Aloha Airlines, Nominal 1-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	90.4 114.5	80.9 100.8	83.3 103.4
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^0$ Tension SBS Dryout	84.1 110.1 106.9 100.5	74.0 84.6 --- 94.9	73.9 99.6 114.4 93.1
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^0$ Tension	0.430 0.286 0.087	0.232 0.139 ---	-0.231 +0.317 0.155
Weight Loss During Dryout	SBS During Dryout	0.94	0.70	1.10

Notes:

* These specimens exposed for 1942 flight hours, 5760 flight cycles, 394 days on aircraft #N73721.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-12. Summary of Results—Aloha Airlines, Nominal 1-yr Interior Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS	84.3	81.4	83.5
	Flexure	107.0	112.4	104.5
	$\pm 45^0$ Tension	112.3	107.6	100.4
	Compression	75.9	102.6	98.6
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS	90.0	76.4	80.0
	Flexure	114.3	102.8	103.6
	$\pm 45^0$ Tension	115.6	87.6	103.0
	Compression	81.9	80.4	76.6
	Stressed Tension	110.4	89.7	109.0
Weight Change Data Percent Gain + Percent Loss -	SBS	0.158	0.068	0.239
	Flexure	0.089	-0.171	0.065
	$\pm 45^0$ Tension	0.044	-0.227	-0.202
	Stressed Tension	0.281	0.099	0.287

Notes:

* These specimens exposed for 1942 flight hours, 5760 flight cycles, 394 days on aircraft #N73721.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-13. Summary of Results—Aloha Airlines, Nominal 2-yr Solar Exposure**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure	73.7 101.3	82.3 103.4	92.1 93.2
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure ±45° Tension SBS Dryout	75.9 96.0 128.2 93.1	59.4 70.9 --- 97.0	64.4 89.7 112.0 94.4
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure ±45° Tension	.475 .977 -.060	.232 .045 ---	.508 .293 .451
Weight Loss During Dryout	SBS Dryout	1.18	.77	1.14

Notes:

* These specimens exposed for 744 days, 3832 hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-14. Summary of Results—Aloha Airlines, Nominal 2-yr Nonsolar Specimen**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS	83.0	80.4	88.5
	Flexure	97.9	107.3	94.5
Elevated Residual Strength Data (% of Baseline)**	SBS	74.6	58.6	65.6
	Flexure	81.5	82.7	87.0
	$\pm 45^{0}$ Tension	96.8	---	112.5
	SBS Dryout	96.9	95.8	91.4
Weight Change Data Percent Gain + Percent Loss -	SBS	.475	.332	.677
	Flexure	-.093	.221	.369
	$\pm 45^{0}$ Tension	.362	---	.472
Weight Loss During Dryout	SBS Dryout	1.04	.76	1.20

Notes:

* These specimens exposed for 744 days, 3832 flight hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-15. Summary of Results—Aloha Airlines, Nominal 2-yr Interior Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^\circ$ Tension Compression	88.4 99.3[+] --- 86.4	84.9 101.5 110.9 100.3	86.1 91.9 107.7 96.9
Elevated Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^\circ$ Tension Stressed Tension Compression	63.5 58.2 126.4 119.8 90.5	65.0 75.1 85.1 95.5 87.5	70.7 84.3 105.3 108.1 79.2
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^\circ$ Tension	.293 .168 .074	.119 -.021 -.126	.372 .133 -.144

[+]These specimens inadvertently tested at 82°C (180°F).

Notes:

* These specimens exposed for 744 days, 3832 flight hours.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-16. Summary of Results—Dryden, Nominal 1-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension	111.5 99.3 104.6	84.1 104.6 110.4	93.2 104.5 104.8
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension SBS Dryout	98.5 106.1 95.8 115.2	79.1 98.8 90.6 92.7	79.8 102.5 95.9 90.8
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^{0}$ Tension	0.052 -0.166 -0.076	0.024 -0.245 -0.114	0.112 -0.101 -0.050
Weight Loss During Dryout	SBS Dryout	.67	.68	.47

Notes:

* These specimens exposed for 433 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-17. Summary of Results—Dryden, Nominal 1-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM 5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Compression	99.2 105.4 96.9	89.5 106.5 105.9	92.0 99.8 97.0
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Compression Stressed Tension SBS Dryout	101.4 112.8++ 78.2++ 105.5 104.2	82.2+ 107.0+ 117.5 91.7 86.2	77.8 107.5 60.7 101.6 88.9
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Stressed Tension	0.095 -0.022 0.121	0.064 -0.129 0.153	0.072 -0.054 0.055
Weight Loss During Dryout	SBS Dryout	.58	.55	.72

\+ Measurement outside 1 standard deviation thrown out.

++ Gripping tab slippage.

Notes:

* These specimens exposed for 433 days.

** Residual strength data based on baseline tests at the respective temperatures.

*Table A-18. Summary of Results—Dryden, Nominal 2-yr Solar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension	101.4 107.8[+] 111.9[+]	94.4 111.1 112.7	93.4 100.2 109.1
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure $\pm 45^{0}$ Tension	104.6 108.4 97.0	87.2 92.6 93.5	86.0 102.7 97.0
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure $\pm 45^{0}$ Tension	+0.007 -0.328 -0.318	+0.010 -0.247 -0.228	+0.073 -0.247 -0.223
Weight Loss During Dryout	SBS Dryout	.38	.21	.38

[+] Average of two measurements.

[++] Dryout oven overheat to $177^{0}C$ ($350^{0}F$), 2 days.

Notes:

* These specimens exposed for 715 days.

** Residual strength data base on baseline tests at the respective temperatures.

*Table A-19. Summary of Results—Dryden, Nominal 2-yr Nonsolar Specimens**

PROPERTY	SPECIMEN CONFIGURATION	MATERIAL SYSTEM		
		5208	5209	934
Room Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Compression	91.7 102.3 91.67	95.2 106.9 100.5	94.6 102.0 102.7
Elevated Temperature Residual Strength Data (% of Baseline)**	SBS Flexure Stressed Tension Compression	99.4 112.3 106.8 88.3	86.3 103.5 89.5 82.6	86.0 106.4 108.3 85.1
Weight Change Data Percent Gain + Percent Loss -	SBS Flexure Stressed Tension	+0.112 -0.474 -0.009	-0.006 -0.259 -0.227	+0.109 -0.184 -0.047
Weight Loss During Dryout	SBS Dryout+	.44	.25	.49

+Dryout oven overheat to 177°C (350°F), 2 days.

Notes:

* These specimens exposed for 715 days.

** Residual strength data base on baseline tests at the respective temperatures.

APPENDIX B

PHYSICAL PROPERTIES AND TEST DATA FOR BASELINE, TIME ALONE, AND WEATHEROMETER INDIVIDUAL SPECIMENS

TABLES

Table B-1. Baseline Short Beam Shear

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
ASBLB00 1	2.4384	6.3754					2377.57	21.1
ASBLB00 2	2.4638	6.3449					2290.83	21.1
ASBLB00 3	2.4943	6.4237					2201.87	21.1
ASBLB00 4	2.5019	6.3297					2233.01	21.1
ASBLB00 5	2.4790	6.3856					2273.04	21.1
ASBLB00 6	2.5019	6.3500					2055.08	48.9
ASBLB00 7	2.6797	6.3144					2201.87	48.9
ASBLB00 8	2.4333	6.3475					2017.27	48.9
ASBLB00 9	2.4867	6.2738					2112.91	48.9
ASBLB00 10	2.4765	6.3678					2179.63	48.9
ASBLB00 11	2.4841	6.2713					1623.60	82.2
ASBLB00 12	2.4384	6.2713					1603.58	82.2
ASBLB00 13	2.4257	6.3754					1741.48	82.2
ASBLB00 14	2.4943	6.3957					2012.82	82.2
ASBLB00 15	2.5273	6.3754					1919.41	82.2
BSBLB00 1	2.6086	6.3983					2035.06	21.1
BSBLB00 2	2.5679	6.2509					1957.22	21.1
BSBLB00 3	2.5806	6.3195					2092.89	21.1
BSBLB00 4	2.5705	6.3373					1977.23	21.1
BSBLB00 5	2.5654	6.2840					1841.56	21.1
BSBLB00 6	2.6467	6.2357					1808.20	48.9
BSBLB00 7	2.6111	6.3119					1772.62	48.9
BSBLB00 8	2.6187	6.3221					1774.84	48.9
BSBLB00 9	2.6238	6.3348					1785.96	48.9
BSBLB00 10	2.4765	6.3246					1692.55	48.9
BSBLB00 11	2.5781	6.3627					1370.05	82.2
BSBLB00 12	2.6568	6.3322					1418.98	82.2
BSBLB00 13	2.6416	6.2459					1421.21	82.2
BSBLB00 14	2.6289	6.3627					1421.21	82.2
BSBLB00 15	2.6162	6.2459					1383.40	82.2
CSBLB00 1	2.7381	6.3754					2604.43	21.1
CSBLB00 2	2.7762	6.3246					2546.61	21.1
CSBLB00 3	2.8219	6.1925					2346.44	21.1
CSBLB00 4	2.7051	6.4211					2357.56	21.1
CSBLB00 5	2.9083	6.2103					2584.42	21.1
CSBLB00 6	2.6924	6.3398					2293.06	48.9
CSBLB00 7	2.8194	6.2967					2317.52	48.9
CSBLB00 8	2.7534	6.3627					2415.38	48.9
CSBLB00 9	2.8067	6.3246					2288.61	48.9
CSBLB00 10	2.8423	6.3805					2344.21	48.9
CSBLB00 11	2.8600	6.3957					2199.65	82.2
CSBLB00 12	2.7813	6.3652					2135.15	82.2
CSBLB00 13	2.8092	6.1087					1781.51	82.2
CSBLB00 14	2.7965	6.3246					1948.32	82.2
CSBLB00 15	2.7711	6.4135					2139.59	82.2

Table B-2. Baseline Flexure

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AFLLB00 1	1.7069	12.6771					638.32	21.1
AFLLB00 2	1.6891	12.7051					644.99	21.1
AFLLB00 3	1.6967	12.7559					627.20	21.1
AFLLB00 4	1.6967	12.6467					611.63	21.1
AFLLB00 5	1.6789	12.6771					620.53	21.1
AFLLB00 6	1.6840	12.7279					618.30	48.9
AFLLB00 7	1.7145	12.7254					638.32	48.9
AFLLB00 8	1.6764	12.7203					551.58	48.9
AFLLB00 9	1.6789	12.7483					638.32	48.9
AFLLB00 10	1.6891	12.7127					629.42	48.9
AFLLB00 11	1.6891	12.7000					560.48	82.2
AFLLB00 12	1.6815	12.5171					580.49	82.2
AFLLB00 13	1.6967	12.7127					582.72	82.2
AFLLB00 14	1.6942	12.6771					573.82	82.2
AFLLB00 15	1.7018	12.6517					607.18	82.2
BFLLB00 1	1.5900	12.6238					556.03	21.1
BFLLB00 2	1.6002	12.5882					540.46	21.1
BFLLB00 3	1.5900	12.7051					564.92	21.1
BFLLB00 4	1.5723	12.6187					544.91	21.1
BFLLB00 5	1.6002	12.6263					569.37	21.1
BFLLB00 6	1.6205	12.4663					527.11	48.9
BFLLB00 7	1.5951	12.5603					502.65	48.9
BFLLB00 8	1.6002	12.5222					533.79	48.9
BFLLB00 9	1.6002	12.6568					542.68	48.9
BFLLB00 10	1.5850	12.5933					533.79	48.9
BFLLB00 11	1.5875	12.4816					444.82	82.2
BFLLB00 12	1.5951	12.5933					473.74	82.2
BFLLB00 13	1.6053	12.6238					458.17	82.2
BFLLB00 14	1.5900	12.6263					493.75	82.2
BFLLB00 15	1.5697	12.5857					473.74	82.2
CFLLB00 1	1.6891	12.5476					600.51	21.1
CFLLB00 2	1.6967	12.7127					658.34	21.1
CFLLB00 3	1.6891	12.6467					709.49	21.1
CFLLB00 4	1.6637	12.6492					669.46	21.1
CFLLB00 5	1.6789	12.6543					665.01	21.1
CFLLB00 6	1.7551	12.6111					669.46	48.9
CFLLB00 7	1.6561	12.6873					629.42	48.9
CFLLB00 8	1.6967	12.7000					656.11	48.9
CFLLB00 9	1.6993	12.5603					656.11	48.9
CFLLB00 10	1.6662	12.6568					658.34	48.9
CFLLB00 11	1.6967	12.5984					607.18	82.2
CFLLB00 12	1.6866	12.6873					584.94	82.2
CFLLB00 13	1.7247	12.6873					649.44	82.2
CFLLB00 14	1.7221	12.7127					611.63	82.2
CFLLB00 15	1.6891	12.6568					660.56	82.2

Table B-3. Baseline ±45-degree Tension

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AT4LB00 1	1.0795	25.3746					4448.22	21.1
AT4LB00 2	1.0617	25.4940						21.1
AT4LB00 3	1.0516	25.4152						21.1
AT4LB00 4	1.0795	25.4533					4270.29	21.1
AT4LB00 5	1.0693	25.3543					4270.29	21.1
AT4LB00 6	1.1074	25.3111					4047.88	48.9
AT4LB00 7	1.0871	25.3746					4025.64	48.9
AT4LB00 8	1.0846	25.4229					4159.09	48.9
AT4LB00 9	1.0820	25.3517					4136.85	48.9
AT4LB00 10	1.0897	25.3365					4047.88	48.9
AT4LB00 11	1.0566	25.3822					3603.06	82.2
AT4LB00 12	1.0820	25.4279					3714.27	82.2
AT4LB00 13	1.0592	25.4432						82.2
AT4LB00 14	1.0643	25.4152					3603.06	82.2
AT4LB00 15	1.0693	25.3009						82.2
BT4LB00 1	1.1024	25.4483						82.2
BT4LB00 2	1.0998	25.4838						82.2
BT4LB00 3	1.1506	25.3416					5382.35	82.2
BT4LB00 4	1.0897	25.4025					4804.08	82.2
BT4LB00 5	1.0897	25.3467					4448.22	82.2
BT4LB00 6	1.1074	25.4508					4626.15	82.2
BT4LB00 7	1.1582	25.3416					5248.90	82.2
BT4LB00 8	1.1659	25.3492					5337.87	82.2
BT4LB00 9	1.1709	25.3441					5560.28	82.2
BT4LB00 10	1.1760	25.3822					5738.21	82.2
BT4LB00 11	1.1024	25.4102						82.2
BT4LB00 12	1.1151	25.4025						82.2
BT4LB00 13	1.1100	25.4000					5137.70	82.2
BT4LB00 14	1.1684	25.3111					5026.49	82.2
BT4LB00 15	1.1405	25.3848					5070.97	82.2
CT4LB00 1	1.1760	25.4025					4759.60	21.1
CT4LB00 2	1.1633	25.4356					4759.60	21.1
CT4LB00 3	1.1760	25.3949						21.1
CT4LB00 4	1.1684	25.4025					4759.60	21.1
CT4LB00 5	1.1684	25.3492						21.1
CT4LB00 6	1.1532	25.4229					4470.46	48.9
CT4LB00 7	1.1557	25.4432					4314.78	48.9
CT4LB00 8	1.1430	25.3721					4492.70	48.9
CT4LB00 9	1.1709	25.3771					4626.15	48.9
CT4LB00 10	1.1684	25.3619					4492.70	48.9
CT4LB00 11	1.1709	25.3822						82.2
CT4LB00 12	1.1379	25.4203					4737.36	82.2
CT4LB00 13	1.1963	25.3492					4804.08	82.2
CT4LB00 14	1.1760	25.4229					4626.15	82.2
CT4LB00 15	1.1405	25.3289						82.2

Table B-4. Baseline 0-degree Compression

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
ACOLB00 1	2.5298	6.1722					24020.40	21.1
ACOLB00 2	2.5806	6.3703					26377.96	21.1
ACOLB00 3	2.5781	6.3678					30136.70	21.1
ACOLB00 4	2.5806	6.2535					28802.24	21.1
ACOLB00 5	2.6746	6.2128					29358.26	21.1
ACOLB00 6	2.5476	6.2687						48.9
ACOLB00 7	2.5756	6.2433					26244.51	48.9
ACOLB00 8	2.6340	6.2967					26133.30	48.9
ACOLB00 9	2.5654	6.3500					24910.04	48.9
ACOLB00 10	2.5222	6.2509					23797.99	48.9
ACOLB00 11	2.5908	6.2230						82.2
ACOLB00 12	2.5248	6.3322						82.2
ACOLB00 13	2.5527	6.2357					18904.94	82.2
ACOLB00 14	2.6137	6.2916					19460.97	82.2
ACOLB00 15	2.5248	6.2763					19460.97	82.2
BCOLB00 1	2.5984	6.2916					26111.06	21.1
BCOLB00 2	2.5629	6.3729					27801.39	21.1
BCOLB00 3	2.5679	6.3271					27022.95	21.1
BCOLB00 4	2.6111	6.3525					26578.13	21.1
BCOLB00 5	2.5502	6.2332					27356.56	21.1
BCOLB00 6	2.5502	6.3195						48.9
BCOLB00 7	2.5832	6.3525					27134.15	48.9
BCOLB00 8	2.5629	6.3983					22574.73	48.9
BCOLB00 9	2.5222	6.3627					25021.25	48.9
BCOLB00 10	2.5908	6.3678					26689.33	48.9
BCOLB00 11	2.5883	6.3805						82.2
BCOLB00 12	2.5705	6.3805						82.2
BCOLB00 13	2.5756	6.3754					21351.47	82.2
BCOLB00 14	2.5730	6.3703					18904.94	82.2
BCOLB00 15	2.4841	6.2636					18126.50	82.2
CCOLB00 1	2.7051	6.3779					30381.36	21.1
CCOLB00 2	2.7203	6.3602					29135.85	21.1
CCOLB00 3	2.5984	6.2255					28802.24	21.1
CCOLB00 4	2.5298	6.4008					27022.95	21.1
CCOLB00 5	2.7737	6.2509					31137.55	21.1
CCOLB00 6	2.7330	6.4287						48.9
CCOLB00 7	2.4638	6.3373					24687.63	48.9
CCOLB00 8	2.7305	6.4211					26911.74	48.9
CCOLB00 9	2.7127	6.4211					29024.65	48.9
CCOLB00 10	2.6899	6.4110					29580.68	48.9
CCOLB00 11	2.7076	6.4338						82.2
CCOLB00 12	2.7178	6.2814						82.2
CCOLB00 13	2.5857	6.4211					24354.01	82.2
CCOLB00 14	2.6365	6.3779					26355.71	82.2
CCOLB00 15	2.4663	6.4237					25799.69	82.2

Table B-5. Baseline 90-degree Compression

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AC9LB00 1	2.4867	6.3906						21.1
AC9LB00 2	2.4892	6.3525						21.1
AC9LB00 3	2.4714	6.2992					3211.62	21.1
AC9LB00 4	2.4917	6.3043					2886.90	21.1
AC9LB00 5	2.4562	6.2967					3127.10	21.1
AC9LB00 6	2.4968	6.3856						48.9
AC9LB00 7	2.4638	6.4059					3091.51	48.9
AC9LB00 8	2.4689	6.2865					2980.31	48.9
AC9LB00 9	2.4867	6.3856					3220.51	48.9
AC9LB00 10	2.4613	1.3462					3625.30	48.9
AC9LB00 11	2.4663	6.3398						82.2
AC9LB00 12	2.4714	6.3932						82.2
AC9LB00 13	2.4486	6.1493					2837.97	82.2
AC9LB00 14	2.4790	6.3754					3100.41	82.2
AC9LB00 15	2.4536	6.2586					2682.28	82.2
BC9LB00 1	2.6543	6.3906					3780.99	21.1
BC9LB00 2	2.6568	6.3703					3447.37	21.1
BC9LB00 3	2.5730	6.3678					3313.93	21.1
BC9LB00 4	2.5603	6.3729						21.1
BC9LB00 5	2.6035	6.3652						21.1
BC9LB00 6	2.6187	6.3068						48.9
BC9LB00 7	2.6187	6.1798					3144.89	48.9
BC9LB00 8	2.6010	6.2840					2926.93	48.9
BC9LB00 9	2.5933	6.3805					3122.65	48.9
BC9LB00 10	2.6162	6.3271					2588.87	48.9
BC9LB00 11	2.5756	6.3957						82.2
BC9LB00 12	2.5705	6.3271						82.2
BC9LB00 13	2.6213	6.2027						82.2
BC9LB00 14	2.6238	6.3830						82.2
BC9LB00 15	2.6187	6.4262					2668.93	82.2
CC9LB00 1	2.3698	6.0731					2526.59	21.1
CC9LB00 2	2.6645	6.3322					3456.27	21.1
CC9LB00 3	2.7102	6.3500					3305.03	21.1
CC9LB00 4	2.6289	6.3348						21.1
CC9LB00 5	2.5883	6.1773						21.1
CC9LB00 6	2.7305	6.1900						48.9
CC9LB00 7	2.6949	6.3398					3033.69	48.9
CC9LB00 8	2.6187	6.1239					3291.68	48.9
CC9LB00 9	2.6213	6.2611					3224.96	48.9
CC9LB00 10	2.6162	6.1366						48.9
CC9LB00 11	2.6264	6.3678						82.2
CC9LB00 12	2.6543	6.0731						82.2
CC9LB00 13	2.6721	6.2433					2731.21	82.2
CC9LB00 14	2.7229	6.3246					3158.24	82.2
CC9LB00 15	2.5121	6.0173						82.2

Table B-6. Baseline Quasi-Isotropic Compression

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
ACQLB00 1	2.5425	6.3424						21.1
ACQLB00 2	2.5375	1.2929						21.1
ACQLB00 3	2.5375	6.3678						21.1
ACQLB00 4	2.5883	6.3094					16502.90	21.1
ACQLB00 5	2.5502	6.4059					17659.44	21.1
ACQLB00 6	2.5248	6.3805					17058.93	48.9
ACQLB00 7	2.6238	6.3525					13900.69	48.9
ACQLB00 8	2.5578	6.3525						-6.7
ACQLB00 9	2.5603	6.3830					14456.77	48.9
ACQLB00 10	2.4867	6.3830					16124.80	48.9
ACQLB00 11	2.5298	6.3932					14901.54	82.2
ACQLB00 12	2.5298	6.3475						82.2
ACQLB00 13	2.5629	6.3830						82.2
ACQLB00 14	2.5400	6.3576					13678.28	82.2
ACQLB00 15	2.5425	6.3729					13678.28	82.2
BCQLB00 1	3.8049	6.3475					14901.54	21.1
BCQLB00 2	3.8024	6.3602						21.1
BCQLB00 3	3.8075	6.3729						21.1
BCQLB00 4	3.7821	6.4008					13233.46	21.1
BCQLB00 5	3.7871	6.2967					14567.93	21.1
BCQLB00 6	3.7821	6.3729					13678.28	48.9
BCQLB00 7	3.5814	6.3221						48.9
BCQLB00 8	3.6500	6.3602					12566.23	48.9
BCQLB00 9	3.8176	6.3449					13789.49	48.9
BCQLB00 10	3.8329	6.3576					11009.35	48.9
BCQLB00 11	3.7846	6.3652					13455.87	82.2
BCQLB00 12	3.7821	6.3779						82.2
BCQLB00 13	3.7770	6.3068						82.2
BCQLB00 14	3.8303	6.3703					11787.79	82.2
BCQLB00 15	3.8024	6.3906					11009.35	82.2
CCQLB00 1	2.8219	6.3779					11676.58	21.1
CCQLB00 2	2.7915	6.2941						21.1
CCQLB00 3	2.7635	6.2789					15235.16	21.1
CCQLB00 4	2.8016	6.2433						21.1
CCQLB00 5	2.7407	6.2408					15679.98	21.1
CCQLB00 6	2.7838	.6279					15791.19	48.9
CCQLB00 7	2.8219	6.2662					14011.90	48.9
CCQLB00 8	2.8677	6.3449					15457.57	48.9
CCQLB00 9	2.8448	6.3576					15457.57	48.9
CCQLB00 10	2.8245	6.2916						48.9
CCQLB00 11	2.7737	6.3754					16013.60	82.2
CCQLB00 12	2.8270	6.3449					15346.37	82.2
CCQLB00 13	2.8473	6.3271					13789.49	82.2
CCQLB00 14	2.8473	6.3449						82.2
CCQLB00 15	2.7534	6.2840					14679.13	82.2

Table B-7. 1-year Time Alone Short Beam Shear

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
ASBLT01 1	2.4994	6.3500					2144.04	21.1
ASBLT01 2	2.4816	6.3475					2081.77	21.1
ASBLT01 3	2.4155	6.3754					2157.39	21.1
ASBLT01 4	2.4740	6.3271					1930.53	21.1
ASBLT01 5	2.4460	6.3627					2188.53	21.1
ASBLT01 6	2.4536	6.3678					1574.67	82.2
ASBLT01 7	2.4105	6.3576					1788.19	82.2
ASBLT01 8	2.4486	6.3602					1903.84	82.2
ASBLT01 9	2.3825	6.3297					1654.74	82.2
ASBLT01 10	2.4867	6.3703	4.1815		4.1772		1823.77	82.2
BSBLT01 1	2.5349	6.3703					1610.26	21.1
BSBLT01 2	2.6238	6.3703					2001.70	21.1
BSBLT01 3	2.6492	6.3271					1868.25	21.1
BSBLT01 4	2.5959	6.3779					1939.42	21.1
BSBLT01 5	2.5959	6.3119					1814.87	21.1
BSBLT01 6	2.6162	6.3322					1361.16	82.2
BSBLT01 7	2.4765	6.1544					1316.67	82.2
BSBLT01 8	2.5730	6.3703					1432.33	82.2
BSBLT01 9	2.6187	6.3221					1450.12	82.2
BSBLT01 10	2.6365	6.3271	4.3458		4.3436		1387.85	82.2
CSBLT01 1	2.7686	6.3170					2419.83	21.1
CSBLT01 2	2.7915	6.2382					2437.63	21.1
CSBLT01 3	2.6721	6.3246					2197.42	21.1
CSBLT01 4	2.6822	6.2586					2348.66	21.1
CSBLT01 5	2.7432	6.3246					2357.56	21.1
CSBLT01 6	2.8016	6.2738					1903.84	82.2
CSBLT01 7	2.8169	6.3373					2117.35	82.2
CSBLT01 8	2.7483	6.2687					1859.36	82.2
CSBLT01 9	2.7559	6.2255					2028.39	82.2
CSBLT01 10	2.7203	6.3297	4.6701		4.6658		2055.08	82.2

Table B-8. 1-year Time Alone Flexure

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AFLLT01 1	1.7272	12.6263					642.77	21.1
AFLLT01 2	1.7018	12.6797					600.51	21.1
AFLLT01 3	1.7120	12.7660					464.84	21.1
AFLLT01 4	1.7145	12.7991					642.77	21.1
AFLLT01 5	1.7145	12.7203					658.34	21.1
AFLLT01 6	1.7018	12.6822					613.85	82.2
AFLLT01 7	1.7297	12.7483					602.73	82.2
AFLLT01 8	1.7043	12.7000					582.72	82.2
AFLLT01 9	1.7018	12.7762					587.17	82.2
AFLLT01 10	1.7272	12.7711	17.8650		17.8335		616.08	82.2
BFLLT01 1	1.6053	12.5781					547.13	21.1
BFLLT01 2	1.6129	12.6797					562.70	21.1
BFLLT01 3	1.6307	12.5222					556.03	21.1
BFLLT01 4	1.6154	12.6035					593.84	21.1
BFLLT01 5	1.6205	12.5730					589.39	21.1
BFLLT01 6	1.6104	12.6035					493.75	82.2
BFLLT01 7	1.6129	12.6289					482.63	82.2
BFLLT01 8	1.6332	12.6314					482.63	82.2
BFLLT01 9	1.6332	12.6517					500.42	82.2
BFLLT01 10	1.6078	12.6187	16.6893		16.6763		493.75	82.2
CFLLT01 1	1.7120	12.6949					685.03	21.1
CFLLT01 2	1.7018	12.6060					689.47	21.1
CFLLT01 3	1.7272	12.5730					633.87	21.1
CFLLT01 4	1.7018	12.7025					629.42	21.1
CFLLT01 5	1.7018	12.6086					538.23	21.1
CFLLT01 6	1.6891	12.7178					596.06	82.2
CFLLT01 7	1.7272	12.6441					609.41	82.2
CFLLT01 8	1.7145	12.6035					662.79	82.2
CFLLT01 9	1.6764	12.6949					558.25	82.2
CFLLT01 10	1.7272	12.7305	17.7038		17.6746		598.29	82.2

Table B-9. 2-year Time Alone Short Beam Shear

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
ASBLT02 1	2.4282	6.3373					2072.87	22.2
ASBLT02 2	2.4435	6.4008					2366.45	22.2
ASBLT02 3	2.4435	6.3576					2201.87	22.2
ASBLT02 4	2.4663	6.2992					2348.66	22.2
ASBLT02 5	2.4206	6.3297					2135.15	22.2
ASBLT02 6	2.5883	6.3703					1850.46	82.2
ASBLT02 7	2.4435	6.3729					1499.05	82.2
ASBLT02 8	2.4435	6.3551					1565.77	82.2
ASBLT02 9	2.4079	6.3500					1770.39	82.2
ASBLT02 0	2.4308	6.2687	4.2125		4.2082		1828.22	82.2
AFLLT02 1	1.7272	1.3030					628.31	22.2
AFLLT02 2	1.7780	12.7787					656.11	22.2
AFLLT02 3	1.7018	12.7000					634.98	22.2
AFLLT02 4	1.7272	12.7229					646.10	22.2
AFLLT02 5	1.7018	12.6822					610.52	22.2
AFLLT02 6	1.6993	12.8041					584.94	82.2
AFLLT02 7	1.7399	12.7000					607.18	82.2
AFLLT02 8	1.7145	12.7991					576.04	82.2
AFLLT02 9	1.6993	12.7457					573.82	82.2
AFLLT02 0	1.7221	12.7813	17.8729		17.8476		598.29	82.2
BSBLT02 1	2.6391	6.3551					1823.77	22.2
BSBLT02 2	2.5400	6.3500					1948.32	22.2
BSBLT02 3	2.6162	6.2738					1903.84	22.2
BSBLT02 4	2.6391	6.3398					1934.98	22.2
BSBLT02 5	2.6416	6.3525					1810.43	22.2
BSBLT02 6	2.5984	6.3449					1321.12	82.2
BSBLT02 7	2.6187	6.2738					1374.50	82.2
BSBLT02 8	2.5781	6.3424					1325.57	82.2
BSBLT02 9	2.5019	6.2281					1178.78	82.2
BSBLT02 0	2.6137	6.3246	4.3423		4.3412		1383.40	82.2
BFLLT02 1	1.6104	12.5679					541.57	22.2
BFLLT02 2	1.6256	12.5451					540.46	22.2
BFLLT02 3	1.6256	12.5349					566.04	22.2
BFLLT02 4	1.6002	12.6492					580.49	22.2
BFLLT02 5	1.6129	12.6695					558.25	22.2
BFLLT02 6	1.6154	12.5882					507.10	82.2
BFLLT02 7	1.6129	12.6771					489.30	82.2
BFLLT02 8	1.6256	12.5933					497.09	82.2
BFLLT02 9	1.5875	12.5349					469.29	82.2
BFLLT02 0	1.6256	12.5019	16.6129		16.5975		504.87	82.2

Table B-10. 2-year Time Alone Flexure

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
CSBLT02 1	2.7915	6.3297					2531.04	22.2
CSBLT02 2	2.8321	6.2484					2588.87	22.2
CSBLT02 3	2.7559	6.3881					2335.32	22.2
CSBLT02 4	2.8956	6.3043					2197.42	22.2
CSBLT02 5	2.7178	6.2992					1886.05	22.2
CSBLT02 6	2.7432	6.2992					1717.01	82.2
CSBLT02 7	2.7559	6.2865					1708.12	82.2
CSBLT02 8	2.7229	6.3805					1739.25	82.2
CSBLT02 9	2.8245	6.3551					1699.22	82.2
CSBLT02 10	2.7610	6.2357	4.7129		4.2311		736.18	82.2
CFLLT02 1	1.7272	12.7051					711.72	22.2
CFLLT02 2	1.7221	12.4460					710.60	22.2
CFLLT02 3	1.7323	12.6721					691.70	22.2
CFLLT02 4	1.7043	12.7508					712.83	22.2
CFLLT02 5	1.7221	12.7559					655.00	22.2
CFLLT02 6	1.7069	12.7051					658.34	82.2
CFLLT02 7	1.7145	12.7406					628.31	82.2
CFLLT02 8	1.7069	12.6492					617.19	82.2
CFLLT02 9	1.7145	12.5755					548.24	82.2
CFLLT02 10	1.7374	1.2522	17.8860		17.8462			82.2

Table B-11. Weatherometer 6-mo Exposure—Flexure

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AFLLWOF 1	1.6916	12.5476	1.7457	1.9997			680.58	21.1
AFLLWOF 2	1.6485	12.6365	1.7553	2.0163			678.35	21.1
AFLLWOF 3	1.6967	12.5781	1.7651	2.0221			656.11	21.1
AFLLWOF 4	1.6967	12.6035	1.7592	2.0186			698.37	21.1
AFLLWOF 5	1.6586	10.4089	2.1747	1.9978			598.29	21.1
AFLLWOF 6	1.6866	12.6873	1.7813	2.0479			665.01	82.2
AFLLWOF 7	1.6993	12.6441	1.7532	2.0240			660.56	82.2
AFLLWOF 8	1.6967	12.5908	1.7755	2.0533			689.47	82.2
AFLLWOF 9	1.6637	12.5933	1.7336	2.0236			656.11	82.2
AFLLWOF 10	1.6662	12.6009	1.7530	2.0670			651.66	82.2
AFLLWOF 11	1.7018	12.6644	1.7808				700.59	21.1
AFLLWOF 12	1.6787	12.7279	1.7988				702.82	21.1
AFLLWOF 13	1.6840	12.4231	1.7387				711.72	21.1
AFLLWOF 14	1.7018	12.7229	1.7933				705.04	21.1
AFLLWOF 15	1.7069	12.6797	1.7934				662.79	21.1
AFLLWOF 16	1.6586	12.7508	1.7805				633.87	82.2
AFLLWOF 17	1.6840	12.7254	1.7790				589.39	82.2
AFLLWOF 18	1.7069	12.7152	1.7986				556.03	82.2
AFLLWOF 19	1.6789	12.7025	1.7759				609.41	82.2
AFLLWOF 20	1.6942	12.7559	1.7851				636.10	82.2
BFLLWOF 1	1.6205	12.5324	1.6600	1.9445	1.9383		549.36	82.2
BFLLWOF 2	1.6129	12.4587	1.6555	1.9456	1.9386		524.89	82.2
BFLLWOF 3	1.6256	12.4612	1.7001	1.9885	1.9827		458.17	82.2
BFLLWOF 4	1.6383	12.5730	1.6778	1.9784	1.9713		538.23	82.2
BFLLWOF 5	1.6637	12.5222	1.6910	1.9919	1.9854		611.63	82.2
BFLLWOF 6	1.5850	12.5806	1.6574		1.6502		464.84	82.2
BFLLWOF 7	1.5977	12.6263	1.6722		1.6651		495.98	82.2
BFLLWOF 8	1.6027	12.4689	1.6433		1.6360		458.17	82.2
BFLLWOF 9	1.5951	12.5857	1.6722		1.6645		471.51	82.2
BFLLWOF 10	1.6002	12.6492	1.6797		1.6726		471.51	82.2
CFLLWOF 1	1.6459	12.6644	1.7614	2.0355	2.0261		682.80	82.2
CFLLWOF 2	1.7247	12.7457	1.8454	2.1052	2.0979		698.37	82.2
CFLLWOF 3	1.7018	12.6949	1.8033	2.0658	2.0581		693.92	82.2
CFLLWOF 4	1.7120	12.6873	1.8261	2.0824	2.0755		662.79	82.2
CFLLWOF 5	1.7501	12.7127	1.8250	2.0927	2.0852		627.20	82.2
CFLLWOF 6	1.6916	12.6517	1.8227		1.8096		651.66	82.2
CFLLWOF 7	1.6789	12.6721	1.8047		1.7917		609.41	82.2
CFLLWOF 8	1.6840	12.5984	1.7617		1.7496		642.77	82.2
CFLLWOF 9	1.7221	12.6365	1.8175		1.8065		373.65	82.2
CFLLWOF 10	1.7018	12.6314	1.8101		1.7971		640.54	82.2

Table B-12. Weatherometer 1-yr Exposure—Flexure

IDENTIFYING CHARACTERS	LAMINATE THICKNESS (MM)	LAMINATE WIDTH (MM)	INITIAL DRY LAMINATE WEIGHT (GRAM)	INITIAL DRY SPECIMEN WEIGHT (GRAM)	EXPOSED SPECIMEN WEIGHT (GRAM)	FINAL DRY SPECIMEN WEIGHT (GRAM)	ULTIMATE FAILURE LOAD (NEWTON)	TEST TEMPERATURE (C)
AFLLW01 1	1.6510	12.6975	1.7600	2.0684	2.0533		515.99	22.2
AFLLW01 2	1.6739	12.5730	1.7286	2.0137	1.9980		513.77	22.2
AFLLW01 3	1.6815	12.6924	1.7790	2.0633	2.0466		709.49	22.2
AFLLW01 4	1.6815	12.6492	1.7685	2.0670	2.0493		595.17	22.2
AFLLW01 5	1.6967	12.5806	1.7613	2.0510	2.0340		494.64	22.2
AFLLW01 6	1.6764	12.6390	1.7753	2.0494	2.0311		572.93	22.2
AFLLW01 7	1.6713	12.6111	1.7568	2.0446	2.0260		710.83	82.2
AFLLW01 8	1.6485	12.6695	1.7459	2.0326	2.0131		647.22	82.2
AFLLW01 9	1.6815	12.5730	1.7655	2.0286	2.0083		708.16	82.2
AFLLW01 10	1.6942	12.6568	1.7819	2.0360	2.0165		717.05	82.2
AFLLW01 11	1.6764	12.7457	1.7907		1.7641		620.53	82.2
AFLLW01 12	1.6764	12.7330	1.7595		1.7314		556.92	22.2
AFLLW01 13	1.6789	12.6975	1.7763		1.7485		549.36	22.2
AFLLW01 14	1.6967	12.7076	1.7924		1.7645		584.94	22.2
AFLLW01 15	1.6739	12.6721	1.7777		1.7496		653.89	22.2
AFLLW01 16	1.7043	12.7432	1.8028		1.7745		493.75	22.2
AFLLW01 17	1.6916	12.7152	1.7814		1.7550		570.26	82.2
AFLLW01 18	1.6789	12.7178	1.7647		1.7381		458.17	82.2
AFLLW01 19	1.6789	12.7279	1.7815		1.7549		521.33	82.2
AFLLW01 20	1.6637	12.6492	1.7624		1.7364		644.99	82.2
BFLLW01 1	1.6205	12.5171	1.6615		1.9079		565.81	82.2
BFLLW01 2	1.6129	12.6644	1.6730	1.9849	1.9727		487.08	82.2
BFLLW01 3	1.6104	12.5933	1.6632	1.9833	1.9703		583.61	82.2
BFLLW01 4	1.6205	12.5882	1.6688	1.0024	1.9877		553.80	82.2
BFLLW01 5	1.6078	12.4460	1.6460	1.9516	1.9383		558.25	82.2
BFLLW01 6	1.5748	12.6644	1.6692		1.6590		488.41	82.2
BFLLW01 7	1.6002	12.6771	1.6772		1.6662		476.85	82.2
BFLLW01 8	1.5977	12.6746	1.6809		1.6703		502.65	82.2
BFLLW01 9	1.6002	12.6619	1.6868		1.6754		480.41	82.2
BFLLW01 10	1.5773	12.4612	1.6478		1.6375		467.06	82.2
CFLLW01 1	1.7043	12.6898	1.7801	2.0363	2.0159		631.65	82.2
CFLLW01 2	1.7120	12.6009	1.7867	1.9358	1.9172		604.07	82.2
CFLLW01 3	1.6205	12.5755	1.7880	2.0374	2.0183		720.61	82.2
CFLLW01 4	1.7196	12.7025	1.8168	2.0883	2.0683		680.58	82.2
CFLLW01 5	1.7170	12.6949	1.8167	2.0749	2.0552		748.19	82.2
CFLLW01 6	1.6840	12.6517	1.7773		1.7457		590.72	82.2
CFLLW01 7	1.6764	12.6416	1.7796		1.7483		574.71	82.2
CFLLW01 8	1.6713	12.6619	1.7748		1.7448		582.72	82.2
CFLLW01 9	1.6815	12.6314	1.7659		1.7359		764.20	82.2
CFLLW02 10	1.6815	12.6365	1.8012		1.7713		590.72	82.2

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Langley Technical Monitor: Ronald K. Clark
Interim Report

16. Abstract

A study is being conducted to determine the effects of environmental exposure on composite materials. The environments considered are representative of those experienced by commercial jet aircraft. Initial results have been compiled for the following material systems: T300/5208, T300/5209, and T300/934. Future results will include AS-1/3501-6 and Kevlar 49/F161-188. Specimens were exposed on the exterior and interior of 737 airplanes of three airlines, and to continuous ground level exposure at four locations. In addition, specimens were exposed in the laboratory to conditions such as: simulated ground-air-ground, weatherometer, and moisture.

Residual strength results are presented for specimens exposed for up to two years at three ground level exposure locations and on airplanes from two airlines. Test results are also given for specimens exposed to the laboratory simulated environments. Test results indicate that short beam shear strength is sensitive to environmental exposure and dependent on the level of absorbed moisture.

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